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HUMAN PERFORMANCE CAPABILITIES IN A SIMULATED SPACE STATION-LIKE ENVIRONMENT
I. FIXED BEAM LUMINANCE AND LOCATION

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ABSTRACT

This investigation determined the effects of a fixed, intense, one-foot diameter beam of simulated sunlight imaged within the field of view, upon responses to a battery of visual, body balance and stability, eye-hand coordination, and mental tests. In addition, each subject's electrocardiogram (ECG) and electrooculograms (EOG, vertical and horizontal) were recorded throughout each day's two-hour testing period within the space station-like environment. The 4,800 foot Lambert luminance beam was imaged upon each of three diffuse, white "work" panels. Since the subject looked only at the central panel the other two side panels acted as peripheral glare sources. This situation is similar to that of an astronaut working aboard an orbiting space station in zero gravity flight with unfiltered or shuttered windows on the day side of the orbit.

The presence of sunlight within the subject's field of view significantly lengthened his response time to red warning lights located in the visual periphery. Sunlight also helped enhance his ability to follow a complex pattern of straight lines accurately and rapidly. The steadiness of visual fixation, eye-hand coordination, and body balance was not appreciably affected by the presence of the sunlight beam, however, the strategy developed by the subjects in visually scanning for selected alphabet letters from among a random matrix of letters was systematically affected as a function of sunlight beam position within the field of view. Results from the hand steadiness test showed a relatively consistent bias to contact the right-hand side of the test hole regardless of which hand or hole size was used but did not indicate any consistent relationship because of illumination condition. Large individual differences were found in the ability to maintain body balance in a number of different one- and two-leg stances, however, the present fixed sunlight beam illuminating the work area did not adversely affect body balance or stability.

Based upon findings from previous investigations it is possible to say that both subjects adapted to the brightly illuminated white panels in approximately 30 seconds after their first exposure each day and thereafter did not experience ocular fatigue, eye strain, or other kinds of disturbances as a result of these viewing conditions.

ABSTRACT

(continued)

The present choice of performance tests proved adequate in most cases, however, several tests could be omitted from the battery in future investigations to save testing time without significant loss of overall performance measurement assessment.

OUTLINE

HUMAN PERFORMANCE CAPABILITIES IN A SIMULATED SPACE STATION-LIKE ENVIRONMENT

I. Fixed Beam Luminance and Location

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This paper describes the first in a series of research projects which determine the human performance capabilities within a work area whose visual characteristics are similar to those expected aboard an orbital space station. The visual characteristic of primary importance is the presence of a beam of simulated sunlight fixed at various locations within the subject's field of view. Later investigations are planned which will quantify his performance capabilities to a spatially and temporally varying beam of sunlight.

This investigation was conducted because of the need for more information about the influence of brightly illuminated areas in one's field of view upon various performance measures. Also of interest was the way in which various sensory and motor (response) systems behave during prolonged exposure to this situation. No laboratory studies could be found which used a variety of performance tests under comparable illumination conditions.

The crew aboard an orbiting space station may be confronted by various kinds of stressors which may degrade their performance on a variety of tasks (refs. 1 - 7). The stressor of primary interest in the present investigation is sunlight entering the station through windows. Current plans for the space station call for the inclusion of "adequate windows arranged to allow both Earth and celestial viewing...of high optical quality...in addition to windows for general viewing and operations." (ref. 8). As will be shown, there are important engineering design considerations of these windows apart from the heat balance, meteroid protection, and radiation protection they afford, namely, <u>their effect upon human visual and other performance capabilities</u>.

If the space station is not rotated to provide artificial gravity and these windows are not shuttered or otherwise filtered, an intense beam of sunlight approximately 30 percent brighter than found on Earth's surface will enter the station's interior and remain stationary or may move slowly across the crew's visual environment. If the space station is rotated to achieve an artificial gravity, this intense beam will enter each window periodically, sweep across the station's interior, and then exit from the window through which it entered. The possible effects of either of these situations are serious and deserve study under carefully controlled laboratory conditions. Hereafter, the non-rotating space station mode of operation is called the <u>zero-g mode</u>; the rotating space station mode of operation is called the <u>rotating mode</u>.

Regarding the effects of sunlight in space, a Soviet article (ref. 9) pointed out that, "The eyes have to perform under the most difficult conditions in space flight: great strain, long periods of weightlessness, the appearance in the port hole field of vision of clouds with a blinding brightness and a background of sky with a very low brightness, the direct penetration of the sun's rays through the port hole into the ship's cabin. All these factors can hinder the work of the operator in fulfilling the flight program." Let us consider the possible effects of this kind of visual environment on body balance and stability as well as upon visual performance capabilities.

Body Balance and Stability:

It is a well known fact that humans obtain information about their environment and their orientation within it from a number of sensory systems. A large body of research has also shown that when these sensory cues for body orientation and localization in space conflict the person can become severely disoriented. The consequences of this disorientation are serious and can lead to mission failure. An example of this situation comes from pilot training flights which point out that moving shadows and bright areas of light moving across the instrument panel can lead to disorientation (ref. 10). In another case (ref. 11) the student pilot remarked ("OH-13, under simulated IFR flight, under the hood), I was flying a basic instrument maneuver. IP (Instructor Pilot) told me to start a left climbing turn. The sun was to our rear.... As I turned, the shadow of the rotor head and rotor mast passed from one side of the instrument panel to the other; giving me disorientation or vertigo."

In the following discussion the possible debilitating effects produced by Coriolis acceleration is acknowledged. And, to whatever degree it is present during the rotating mode, it is assumed that it will further degrade the crew's performance until adequate adaptation is achieved.

Aside from the mental (i.e., intellectual, cognitive, etc.) capabilities required to perform various tasks aboard an orbiting space station, the astronaut must be able to: (1) maintain his body orientation, his sense of body balance and equilibrium, and limb coordination, and (2) perform fine muscular movements. Since precise muscular movements require a high degree of eye-hand coordination it is important to investigate the essential sensory cues required to achieve optimal performance.

Regarding the first case, whole body orientation within a relatively small, enclosed space such as the space station will be largely a matter of using visual cues during the zero gravity space station mode. This is, of course, due to two factors: (a) vestibular cues will be absent, and (b) a man, free-floating inside the space station, will not have as many tactual cues available as a man experiencing gravitational force. If the space station is rotated to produce some level of "artificial gravity" then other sensory cues such as proprioception, vestibular, tactual, etc., will become more important. The essential point is that vision will play the dominant role in providing for the astronaut's equilibrium, whole body orientation, and sense of balance aboard an orbiting space station.

Regarding the second case, precision muscular movements require finely tuned visual and neuromuscular feedback mechanisms and, to some extent, tactual cues as well. Precision eye-hand coordination relies upon vision regardless of the presence or absence of gravity.

Visual Effects:

There is reasonable evidence in the scientific literature to expect that the presence of this fixed (or moving) bright beam of sunlight will bring about a reduction in visual performance due to transient changes in visual (threshold) sensitivity, glare, after images, ocular fatigue, large changes in pupillary area, blinks and voluntary eye closures, visual distraction, and even possible short-term optokinetic nystagmus. If sufficient conflict is developed between visual, vestibular, and other sensory cues, nausea, vertigo, or whole-body disorientation could result. It may also be expected that several kinds of visual illusions could be experienced in this kind of visual environment as well, e.g., apparent movement, deviation of the perceived vertical from the artificially induced local vertical, etc.

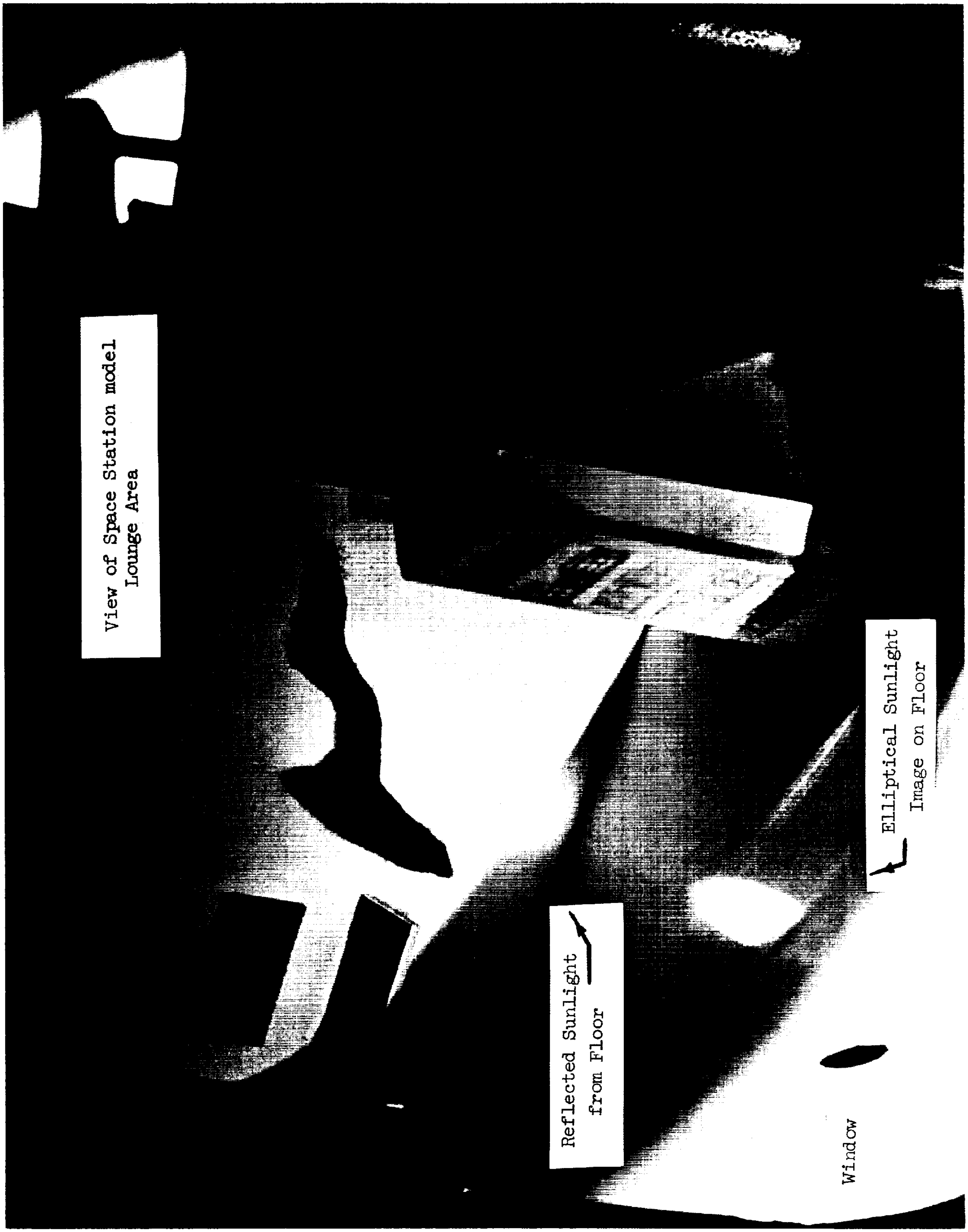
Extensive literature reviews on the subject of glare and various visual responses are found elsewhere (refs. 12 - 14). They emphasize the fact that glare refers not just to an experience associated with the absolute brightness one encounters but to the distribution of luminance in the visual field as well. Also, the state of light adaptation of the subject's eyes also may cause one visual environment to appear "glaring" and another not "glaring." Therefore, the choice of the space station's interior "ambient" illumination level(s) is extremely important in controlling for glare-related performance decrements. The primary purpose here, however, is to research the effects of a fixed beam of sunlight upon various performance measures so that various window filters, shutters, and other light control equipment can be designed to help optimize the crew's vision.

Space Station Interior Illumination Simulation:

In order to gain a better idea of the kinds of design problems to be met in planning for the control of sunlight within the space station, a station model was constructed and photographed under simulated solar illumination conditions. Each of these photographs illustrates a particular feature of the interior illumination problem to be met by the crewmembers. The crew will have to carry out their various duties as best they can in the presence of the sunlight beam or else change the interior illumination to suit their current tasks. The need for adaptability of the various light control equipment is emphasized. And, although the crew may need to completely shut off the sunlight at certain times, they might also need to admit this potentially useful source of illumination.

Figure 1 shows a beam of sunlight which has entered one of the windows in the lounge area and which strikes the diffuse, white floor as an ellipse and then reflects up again upon the far wall.

Figure 1


View of Space Station model
Lounge Area
Elliptical Sunlight
Image on Floor
Reflected Sunlight
from Floor
Window

In Figure 2 the model has been rotated so that the unfiltered sunlight beam impinges upon both the floor and the far wall. And, as the station is rotated even farther - as it would do continuously each revolution during the rotating mode many times each minute - the beam's image becomes more circular once again upon the far wall.

The interior illumination shown in Figure 3 was produced by placing a semi-diffuse milk glass filter at the window. This illustrates how sunlight might be managed to provide relatively even illumination for the crew; power requirements for ambient illumination could be reduced if sunlight could be diffused at the space station windows.

Figure 2 about here

Figure 3 about here

Figure 4 illustrates how a single beam of sunlight can be broken up into multiple images as it passes through the station's interior. In this view the beam is entering through a window (out of sight at the bottom), impinges upon an overhanging cabinet, a vertical rack, and finally upon another rack

Figure 4 about here

mounted upon the far wall. The large number of variations of this kind of illumination geometry make it very important to properly design window filters or other light control equipment prior to the flight.

A single beam of sunlight is shown entering the window at the lower left of the photograph in Figure 5. It falls obliquely upon a work table top and also, some distance away, upon the station's floor. Extremely high visual contrasts can be expected on work surfaces if a relatively low (e.g., 5 foot candles) ambient illumination level exists. This situation can seriously affect a number of visual functions.

Figure 5 about here

These fixed or moving bright patches of light most likely will be distracting to the crew and may cause the crew to either shutter the beam off completely or move their work to areas that are not directly within the sunlight.

This photographic demonstration of some of the space station interior illumination problems also points up the importance of the correct choice of interior surface finishes. Figure 6, for instance, illustrates how a beam of unfiltered sunlight will reflect off glossy surfaces to create multiple "secondary" glare

Figure 2

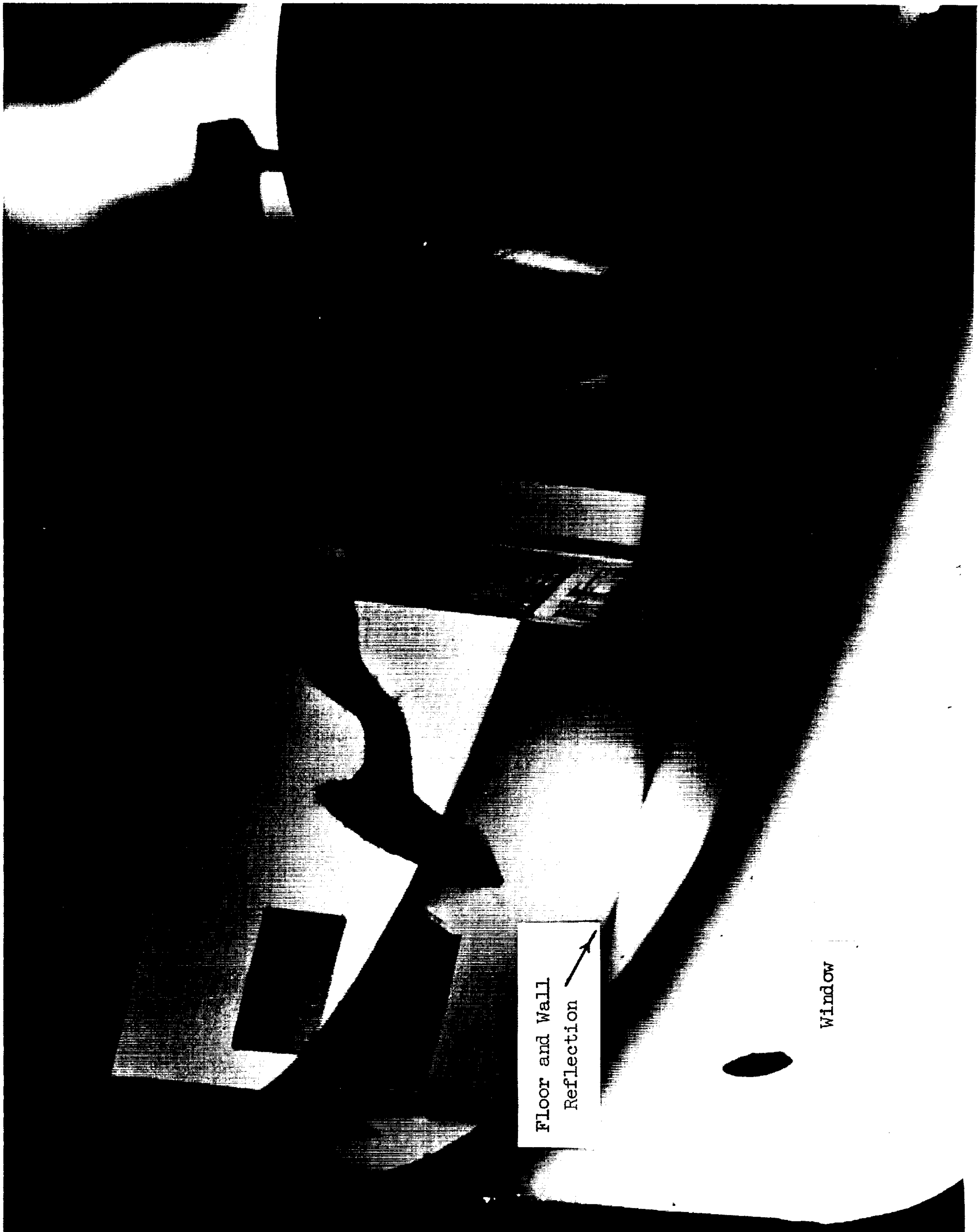


Figure 3

Figure 4

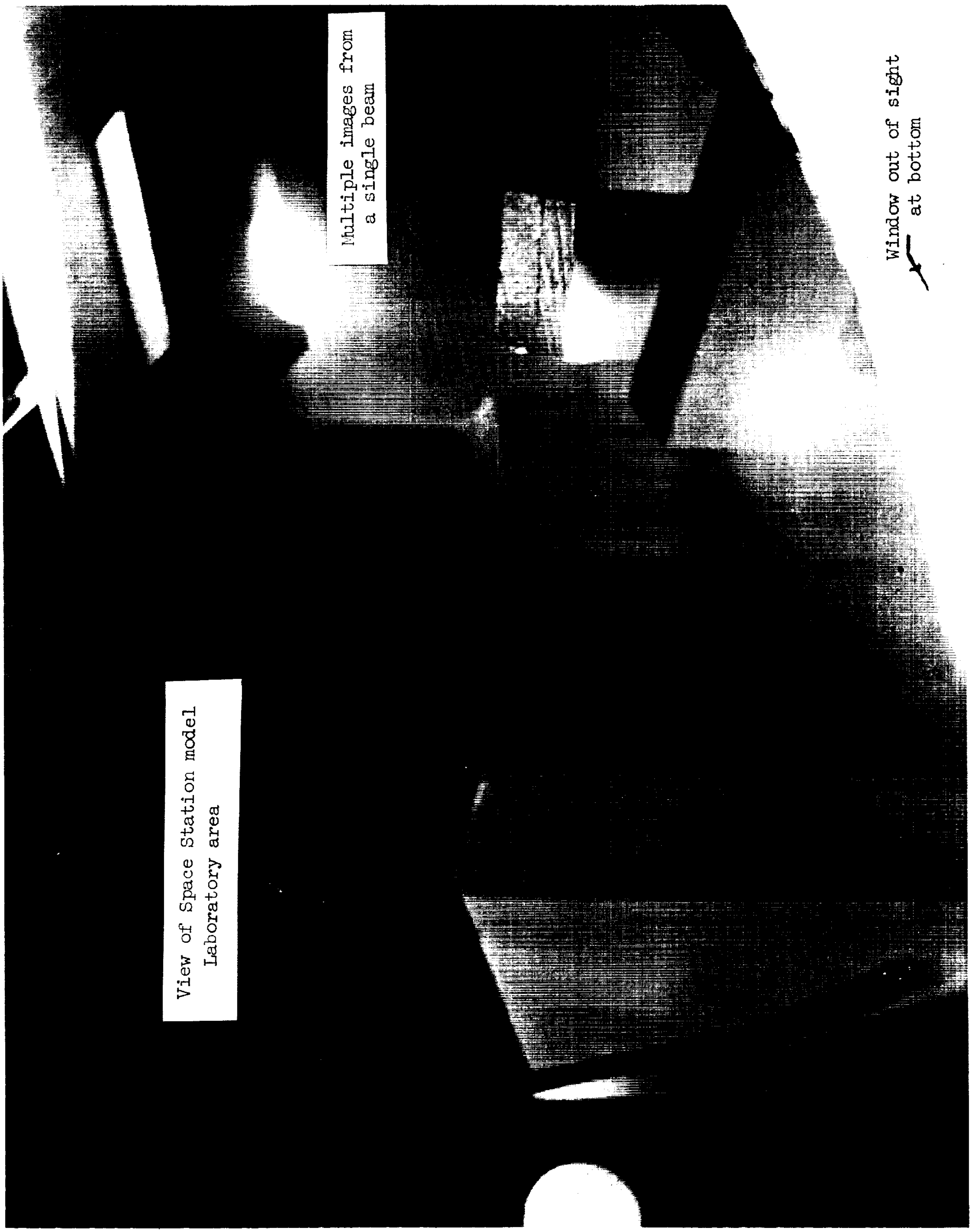

Multiple images from a single beam
Window out of sight at bottom
View of Space Station model Laboratory area

Figure 5

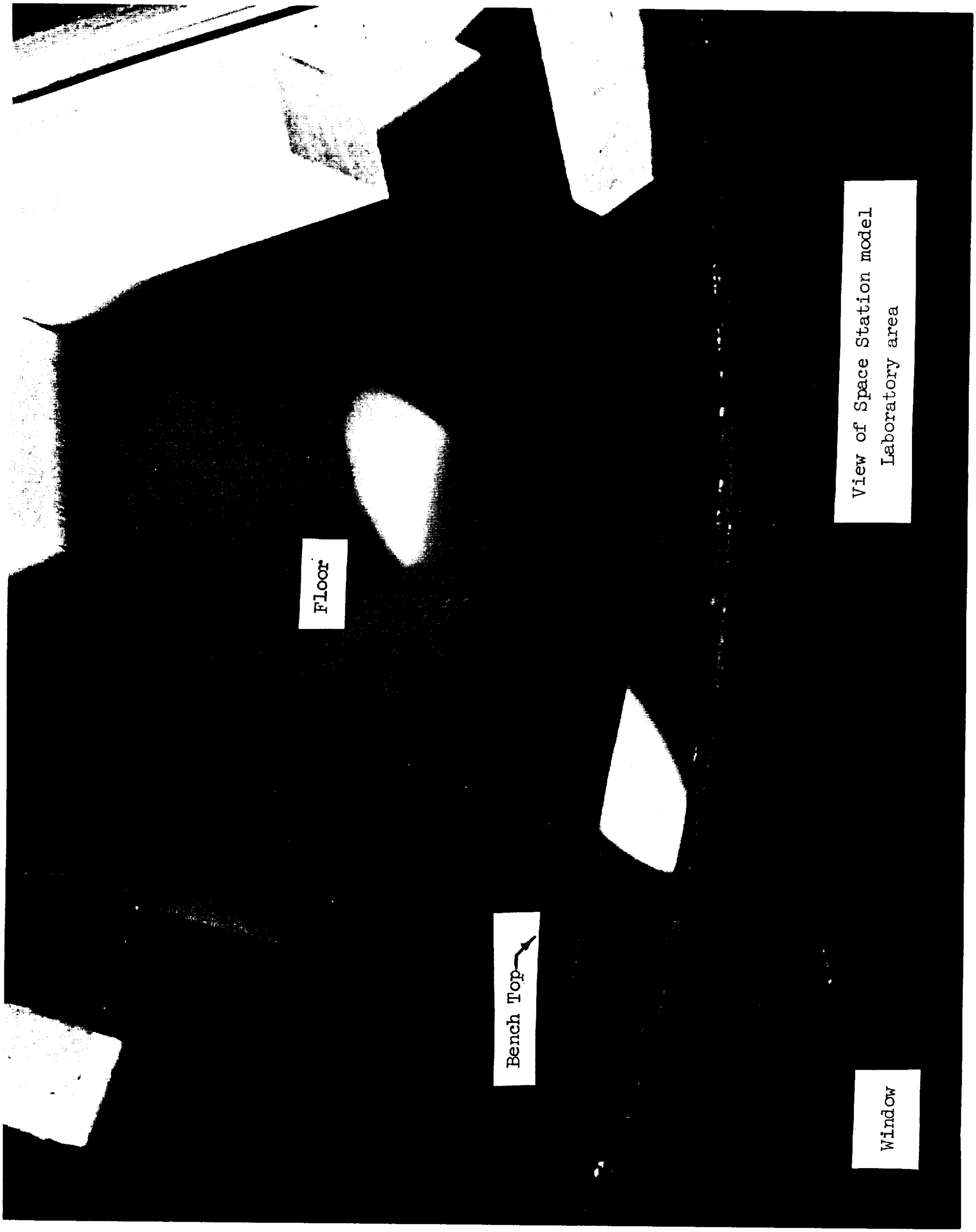
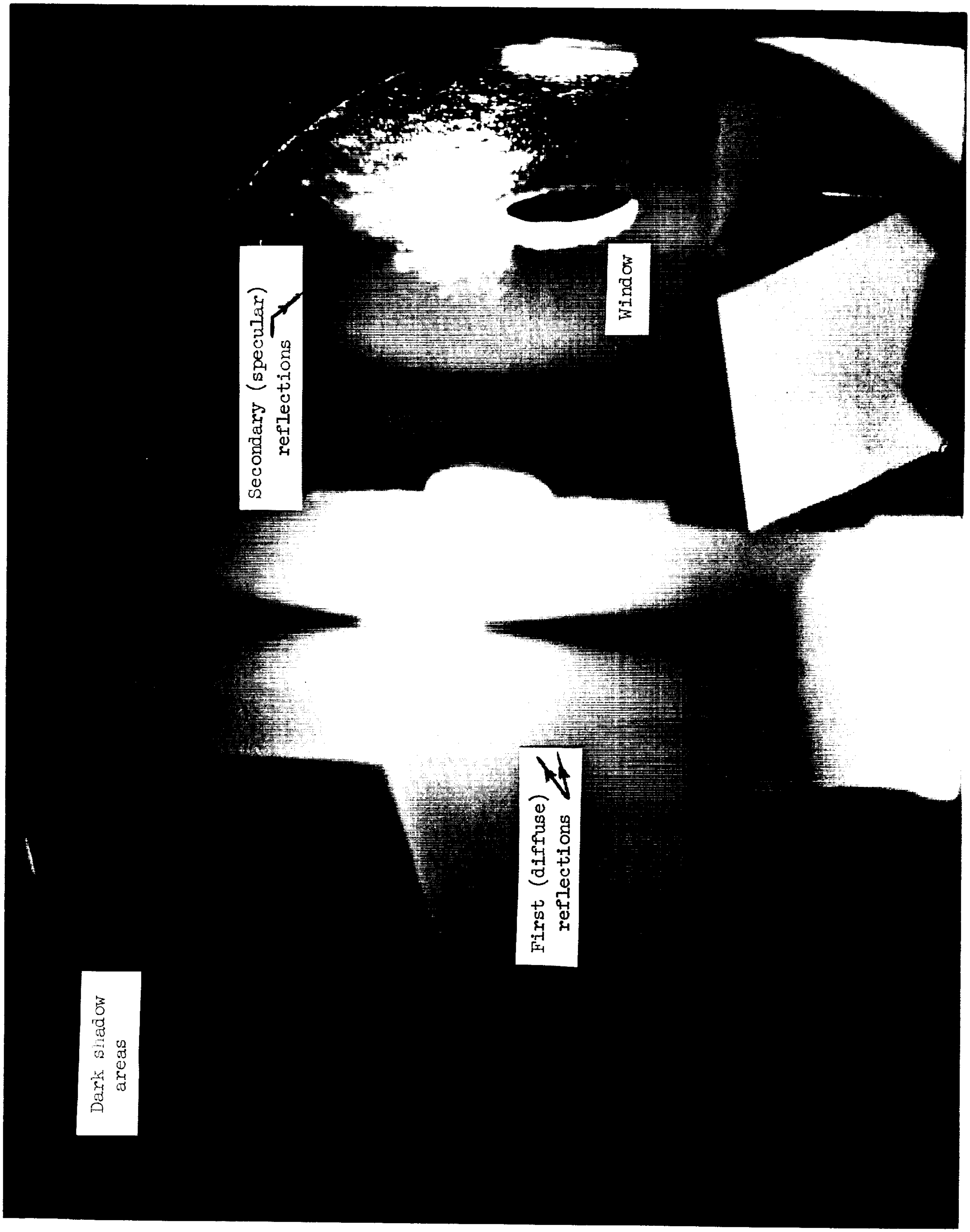

View of Space Station model
Laboratory area
Floor
Bench Top
Window

Figure 6


Secondary (specular) reflections
Window
First (diffuse) reflections
Dark shadow areas

sources for the crew. These preliminary photographs would tend to suggest that little if any of the station's interior should possess a "hard gloss" (specular reflecting) surface finish unless it is first shown that there is no possibility of sunlight falling directly upon that surface. Although there are many such design recommendations which might be made from these kind of simulations it is more reasonable to conduct controlled scientific investigations of human performance capabilities in these kinds of visual environments.

An investigation is described next which had as its major objective the establishment of basic relationships between various performance measures and a fixed beam of simulated sunlight falling upon various locations within the subject's field of view.

Method

Laboratory Facilities and Procedures:

Laboratory: This investigation was conducted within the Ames High Luminance Vision Laboratory clean room described elsewhere (ref. 15). This room had a relatively constant air temperature (68°F, ±2°) and humidity (45 percent ±1 percent). The room had been qualified as a class 10,000 clean room insuring that there was essentially no visible airborne particulate matter. Therefore, the solar radiation which was directed into this room was not visible except when the beam reflected off a surface. The floor dimensions were approximately 10' x 18'. All wall surfaces were diffuse black with about 2 percent reflectivity. All surfaces upon which the beam of sunlight could reflect were diffuse reflectors, i.e., there were no specularly reflecting surfaces present which could reflect the sunlight back into the subject's eyes. Figure 7 presents a schematic illustration of the High Luminance Vision Laboratory.

Figure 7

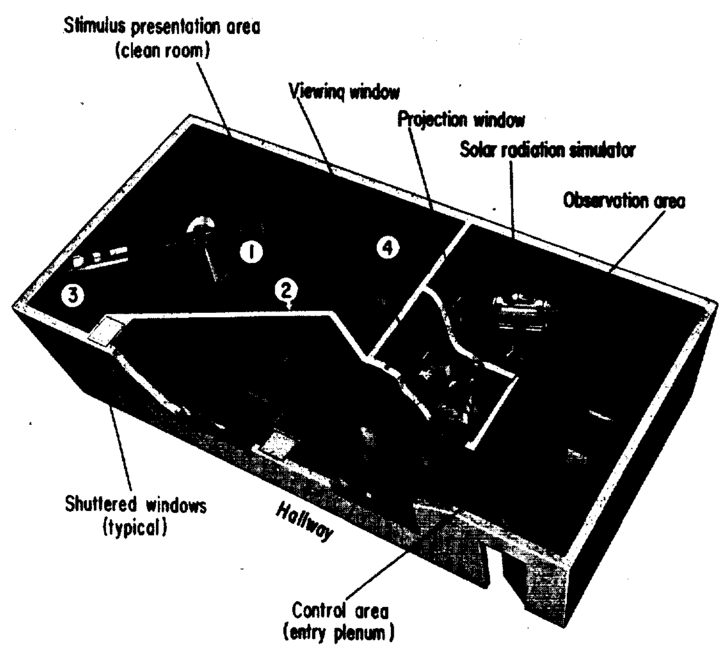


Figure 8 shows the main laboratory control area from which the various tests were coordinated. The subject was under constant surveillance by an experimenter through a small, one-way window into the clean room. The subject and all experimenters were in constant communication via an intercom; all verbalizations were recorded on magnetic tape.

Figure 8

The beam of simulated sunlight was produced by a Genarco carbon arc (5800^{o}K), model ME4W, water cooled projector shown in Figure 9. It produced a 12"

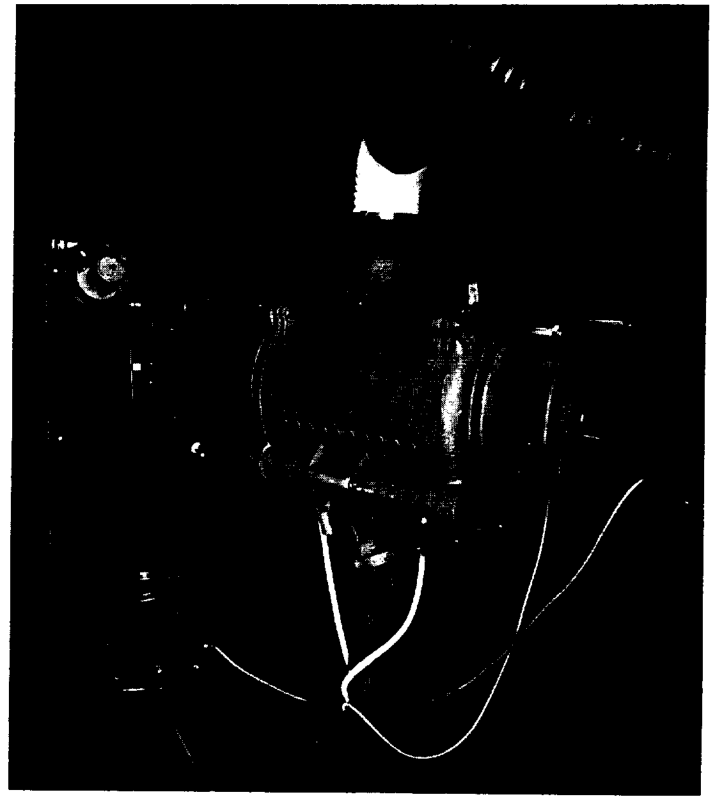


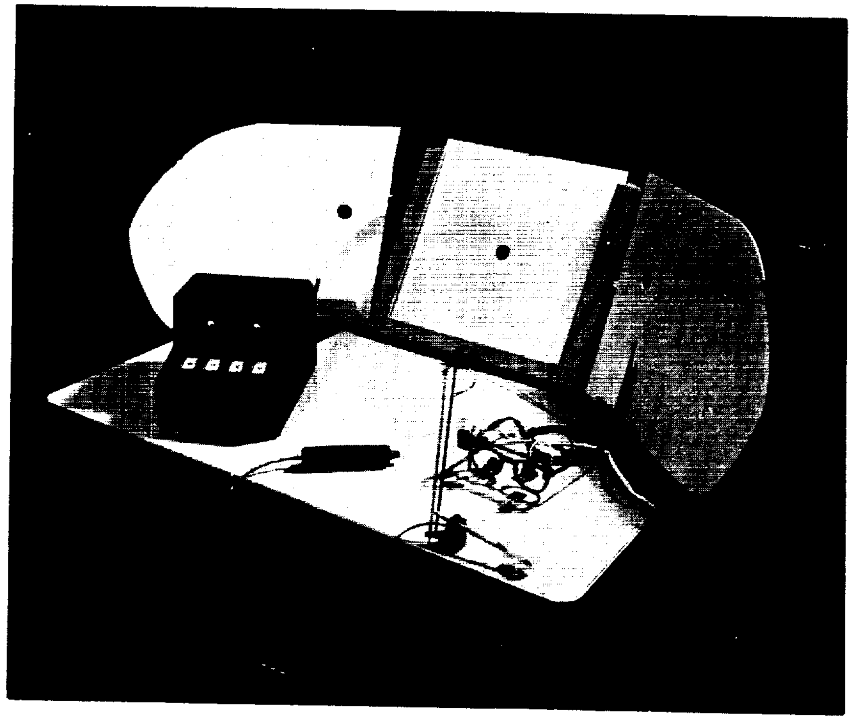
Figure 9

diameter collimated beam having an unfiltered spectral bandpass of from 0.25 to beyond 2.5 microns. The rated radiant energy of this simulator operated at 160 amperes and at 0.5^{o} half angle of beam divergence is 1760 watts per square meter. For the present testing, however, a metal oxide glass filter was placed in the beam to reduce the infrared and ultraviolet radiation to safe levels. A number of other safety precautions were carried out in order to insure completely safe operation of this light source.

The subject's work station, at which he performed most of the performance tests, is shown in Figure 10. It consisted of a small table, 14" x 14" stimulus card rack (center), two diffuse white cardboard side panels, and other stimulus and response equipment described below.

For the foveal illumination test condition the 12" diameter beam of sunlight was shown directly upon the center of the middle panel. Therefore, each corner of this panel was less intensely illuminated than was the center. Luminance over the central 95 percent of this panel (under sunlight) was 4800 foot Lamberts. For the parafoveal-right and parafoveal-left illumination test condition the beam of sunlight was shown upon the right- and left-hand panels respectively.

Figure 10



Because the three white panels were not completely diffuse reflectors and were oriented at different angles with respect to the beam direction - relative to each other - each panel possessed different luminance values across their faces. The parafoveal right panel, for instance, possessed luminances ranging from 1530 foot Lamberts at the far right to 2700 foot Lamberts at ~~its~~ far left. The parafoveal left panel possessed luminances ranging from 10,000 foot Lamberts at the far right to about 6200 foot Lamberts at its far left. The luminance at the center of the right-hand panel was 2500 foot Lamberts, the luminance at the center of the left-hand panel was 7000 foot Lamberts. These photometric values are considered to be accurate to about 4 percent ($\pm$ 100 ft-L) due to instabilities in the burning rate of the carbons.

In addition, there were various shadows cast upon the face of the parafoveal left panel by the subject's right shoulder, the Ames Crew Evaluator (ACE) response box and the edge of the wall opening through which the solar simulator beam was shown. These shadows created a complex visual scene which is difficult to describe fully. To provide an indication of the contrast resulting from the various shadows present upon the left panel, a luminance value of 6424 foot Lamberts was read just above the ACE box shadow in full sunlight (L_t). A luminance value of 55 foot Lamberts was read from the darkest portion of this shadow region (L_b). Using the standard formula for contrast $C = \frac{L_t - L_b}{L_b}$, C = 115. The subject was instructed not to look at either of the two side panels during testing. Also, the location of all of the shadows upon the parafoveal left panel remained fixed throughout this investigation except for minor changes in the position of the shadow cast by the subject himself.

The following physiological measures were monitored throughout this investigation. The subject was instrumented for an electrocardiogram (ECG) using standard electrode placement: high signal lead at sternum, low signal lead on his left side at the level of the last intercostal and mid-line neck ground. The electrooculographic potential (EOG) was recorded for both horizontal and vertical eye movements. Horizontal eye movements were monitored by two electrodes, each located at the temporal canthus of each eye. Vertical eye movements, blinks, and eye closures were monitored by two electrodes, one located between the eyebrow and eyelid (superior electrode), above the right eye, the other located on the vertical midline through the cornea just beneath the right eye.

After the physiological electrodes were applied the subject and experimenters entered the laboratory where they donned their black, clean room garments. The subject was then led into the clean room area and a back-mounted, electrode plug-in box was strapped to his back. This box is shown in Figure 11. This box was, in turn, connected by a long, flexible cable to the amplifiers and recorders. This cable allowed the subject freedom of movement during sitting, standing, and walking tests.

Figure 11

During the Visual Search Strategy Test (VSST), the subject wore a pair of spectacle frames upon which were mounted eye point of regard (infrared) sensors (refs. 16 - 17). These can be seen in Figure 10 (center-right on table top) and also worn by the subject in Figure 11. In addition to the spectacle frames, the eye point of regard measurement system required that the subject bite upon a wax dental impression which was, in turn, attached to an X-Y potentiometer and telescoping rod assembly. This equipment made it possible to monitor his head position and thereby determine his resultant line of sight.

Description of Tests and Instructions:

The tests which were administered were chosen because they sampled a wide range of performance capabilities related to the kinds of activities likely to be found aboard a space station during both on- and off-duty hours. Table 1 presents a list of these tests and related information.

Table 1

Tests Administered

Name of Test (T)	Abbreviation	Nominal Administration Time (mins.)
1. Visual Acuity	VAT	5
2. Visual Fixation Steadiness	VFST	6
3. Peripheral Response Time	PRTT	15
4. Visual Tracking (straight lines)	VPT	5
5. Visual Tracking (curved lines)	RPT	5
6. Visual Search Strategy	VSST	30
7. Hand Steadiness	HST	20
8. Body Balance Battery	BBB	12
9. Precision Eye-Hand Coordination	DT	2
10. Ames Crew Evaluator	ACE	15
		Total = $1^h\ 55^m$

1. Visual Acuity Test: (VAT-OS, OD)

Visual acuity is the ability of the visual system to correctly resolve two elements as separate from each other. Because acuity can be related to so many everyday tasks, it has received a great deal of attention by researchers.

Excellent literature reviews are available elsewhere (refs. 18 - 21). As Westheimer (ref. 21) and others have pointed out, acuity is independent of illumination level over a rather wide range of illumination, i.e., from about the rod receptor threshold (about $-2 \log_{10}$ ml) to about $2 \log_{10}$ ml (ref. 22, pg. 385). An experimental question can be raised here. Under the high luminance conditions expected aboard a space station, will acuity be adversely affected?

Apparatus and Instructions. The acuity test consisted of a specially prepared set of Landolt C (broken ring) patterns photographed on diffuse, white photographic paper and mounted on a 14" x 14" cardboard. All 64 test patterns possessed the same contrast as did the other vision tests using the 14" x 14" stimulus cards with black patterns. The following acuity gap sizes were used (20:50, 20:42, 20:38, 20:33, and 20:25) with a viewing distance of 36 inches.

Each of the broken ring patterns was located at the intersection of one of four concentric circles having radii of 1.5, 3.0, 4.5, and 6.0 inches from the card's center and one of 16 radial lines, each 22.5° apart around the 360°. Each ring pattern had either one or two gaps according to a random order. These gaps occurred at eight possible locations, 45° arc apart around the ring. A total of six, same-gap-size patterns were located in the same groups (progressing around each circle) after which six next smaller gap size patterns were included, and so on.

Because the cardboard mounting was square it could be rotated into each of four different orientations during testing. Both eyes were tested separately each day; a different stimulus card orientation was used for each eye. The only restriction upon card orientation randomization was that all four orientations had to be completed before a new set of four random orientations could be presented to the subject.

The subject was instructed to wear an eye patch over the non-viewing eye and leave both eyes open. Viewing distance was checked just before testing each eye. The subject sat in a comfortable chair with no rigid head support, therefore viewing distance probably varied as much as one inch. The experimenter called out a number (from one to 16) and a letter (from A to D) to indicate to the subject the intersection location where the broken ring pattern of interest could be found. This administration technique allowed the experimenter to present a variety of presentation orders without providing cues to the subject about the next pattern to be viewed. The data analysis indicated no learning effect over this two-month study.

The subject was instructed to call out the clock-face position of the gap(s) in the broken ring pattern indicated. These subjects typically responded in about 1 second; a complete administration of this test to one eye required about 1.75 minutes. Viewing eye test order was randomized each day. Five same-gap-size acuity patterns were presented each day to each eye using the 20:33, 20:30, and 20:25 gap sizes. This amounted to a total of 120 responses per subject per week or 900 responses collected per entire experiment.

2. Visual Fixation Steadiness Test: (VFST)

The objective of this test was to determine how stable one's visual fixation (line of sight) could be maintained under these illumination conditions for binocular vision and the head and body free to move. One investigator (ref. 23, pg. 615) confirmed the findings of previous researchers (refs. 24 - 26) that rapid eyeglobe movements (called flicks) during voluntary fixation ranged in amplitude from 1 to 20 min. arc; slow drifts of from 1 to 5 min. arc occurred between flicks. A corrective eyeglobe movement occurred when the target's retinal image reached the approximate edge of the central fovea (approximately 100 μ diameter; Polyak's foveola)(ref. 27).

Apparatus and Instructions. During this 5 minute long, timed test the subject stood 127 inches away from a point source of light viewed against a black background. Its luminous intensity was equivalent to a +2 (visual) magnitude star. He was instructed only to maintain his gaze upon the star until told to relax. No warning was given prior to terminating the test. The experimenter checked the subject's body sway periodically. The subject's heart rate and blink rate was also recorded and analyzed.

Fixation stability was monitored using the horizontal and vertical EOG equipment. Silver-silver chloride electrodes were used in conjunction with a Beckman (type 9859) Direct Nystagmus Input Coupler, type 481B preamplifier, and type 482A amplifier at a (typical) gain of 10 mv per cm. An angular resolution of eyeglobe movement relative to the skull of approximately 1^{o} arc in the vertical and 1.5^{o} arc in the horizontal was achieved.

3. Peripheral Response Time Test: (PRTT)

There are many situations in both aeronautics and astronautics which require the pilot to monitor warning display lights at various locations within his visual field. When a warning light comes on there is usually a minimum amount of time in which the pilot must respond appropriately. This type of situation would not be particularly difficult if monitoring these various warning lights were all he had to do. But he must also perform other flight-related duties. This test was included in order to determine if any decrement in response time occurs because of the presence of the bright beam of sunlight imaged within the field of view while the subject is occupied with an ongoing primary visual search task.

That such a decrement could occur would be predicted from the results of several earlier studies. Leibowitz and Appelle (ref. 28) reported that luminance thresholds increased as the complexity of the central fixation light and the complexity of the subject's responses to the light increased. Similarly, Webster and Haselrud (ref. 29) showed that the subject's accuracy in reporting the absence or presence of peripheral stimuli decreased when they counted auditory clicks or the flashes of a foveal fixation light. Bahrick, Fitts, and Rankin (ref. 30) demonstrated that the accuracy of peripheral detection decreased when performance on a central task was improved by incentives. Mackworth (ref. 31) reported that the functional visual field may appear to expand or contract depending upon the information loading of the task. A significant increase in peripheral response time to flashed point sources was found by Haines (ref. 32) when an intense glare source was located close to the subject's fixation point and which cast a veiling luminance over his field of view.

The studies cited above would lead to a prediction that detection of peripherally located test lights might be interfered with by illumination upon the subject's work area, or imaged visually near it, and thereby lead to a decrement in his performance.

Apparatus. The apparatus consisted of a perimeter upon which each of the eight stimulus test lights were mounted, a response button, and appropriate controls and timing equipment. The perimeter consisted of an aluminum U shaped channel bent to a constant 2 foot radius. Each of the three white diffuse panels were located in front of this perimeter and 1" diameter holes were made in these panels just in front of the 30^{o} left, 30^{o} right, and 0^{o} test lights. Figure 11 shows an experimenter pointing out the 0^{o} test light to a subject.

The test lights were located along the horizontal semi-circle at 30^{o}, 60^{o}, and 90^{o} to the right and left of the central fixation point (0^{o}). An additional test light was located 30^{o} arc vertically above the 0^{o} test light. The subject voluntarily maintained his head position at the intersection of the two 90^{o} lights throughout this test, thereby maintaining an almost constant viewing distance of 24".

The test lights were 0.63" diameter, Dialco pilot lamps with standard red plastic lens caps. Each lamp subtended an angle of 1^{o} 30' arc diameter. The results of a photometric calibration of each test light is presented in Table 2. As is indicated, the lamps were matched for approximately equal luminance at

Table 2

Photometric Analysis of Test Lights Used in the PRTT

Lamp Position+	Luminance (ft-L)*
90^{o}L	117.4
60^{o}L	106.1
30^{o}L	84.5
0^{o}	95.8
30^{o}R	82.4
60^{o}R	105.0
90^{o}R	112.3
30^{o} up	89.6

Table 2 (continued)

+ L = left of 0^{o} test light; R = right of the 0^{o} test light
Spectra

* Measured with Pritchard photometer, 0.5^{o} aperture, short focal length lens. Nominal measurement accuracy ±5 percent. Each value based upon the mean of three readings.

comparable angular separations from the 0^{o} fixation position.

A 14" x 14" stimulus card was located at the center of the subject's visual field while he fixated the 0^{o} test light. This card was similar to those used in the Visual Search Strategy Test except that a 1" diameter hole was made at its center and a different random alphabet order was used. At the present viewing distance, the inter-letter horizontal and vertical spacing was 6^{o} arc. The visual angle from the left- to the right-hand columns of letters and top to bottom row of letters was 22^{o} 37' arc. The visual angle from one corner letter to the opposite, diagonal letter was 30^{o} 30' arc. The diagonal distance from any letter to any adjacent letter was 8^{o} 27' arc.

In order to provide a centrally located ongoing visual search task for the subject, an experimenter called out a letter approximately once every three seconds. The subject was instructed to visually search for this letter and, after locating it, to fixate it for one second. He was then to refixate the 0^{o} test light position until the next letter was called out. This testing procedure not only simulated the approximate kinds of search tasks found in many aerospace situations but also provided an indication of the subject's fixation position, i.e., it made it possible to say that the subject did not look directly at the peripheral test light when it appeared.

Administration of the individual peripheral test lights was done at variable intervals varying from 6 to 10 seconds (mean = 8 sec.). The response timer started when the light appeared and stopped when the subject depressed his response button. If the subject did not respond within 4 seconds after the light appeared the test light was extinguished and an error was recorded for that trial.

Experimental Design. Each subject made 15 responses to each of the eight test lights for a total of 120 responses per day. Test light presentation order was randomized. Each test session required about 15 minutes per day. Each subject was tested under each of the four illumination conditions as described previously.

4. Visual Tracking (Straight Lines): (VPT)

In this test the ability to visually follow lines rapidly and accurately through an entangled network of lines was measured using the Visual Pursuit Test (VPT) of the Employee Aptitude Survey (EAS). This survey consists of 10 short, pencil-paper tests of which the present VPT is test number 3.

This test battery has been reviewed in both the Fifth and Sixth Mental Measurements Yearbooks (refs. 33 - 34). It is described as a well constructed, convenient battery of tests. However, no specific comments are given for the VPT alone.

The literature contains only one study using the VPT. The test was given to a group of 100 freshmen nursing students by Michael, Haney, et al. (refs. 35 - 37) and was not found to be a significant predictor of success in nursing.

<u>Apparatus and Instructions</u>. This test consists of 30 lines arranged on an 8-1/2" x 11" sheet of paper in a complex schematic diagram and is specifically designed as a selection instrument for technical positions requiring the use of "schematic" type material. Each line runs from a number on the right side of the sheet to a specific letter answer box on the left side. Five answer spaces (A,B,C,D,E) are located on the right side of each number. The subject blackens the correct answer space for that line.

The instructions were as follows: "Before you is the Visual Pursuit Test sheet. Read through the printed instructions and complete the practice problems."

After the subject had finished the 4 practice problems, he was given the correct answers for them and asked if he had any questions. When the experimenter was sure the subject understood the task, he was given these final instructions:

> "On the other side of the sheet are more lines like those you have just traced. When I tell you, please turn your sheet over and I will start you on the test. You will be given five minutes to trace as many lines as you can. Work as quickly and as accurately as possible. You will do better if you follow the lines through with your eyes, not your pencil. If you finish before time is called, please call out 'End' into your microphone. Do you have any questions? Turn your paper over, ready, begin."

5. <u>Visual Tracking (Curved Lines)</u>: (RPT)

This test required that the subject be able to visually follow each of ten continuously curving lines (starting on the left) through a maze of other curved lines to the correct answer space on the right side of the maze. It was assumed that by presenting a series of five, complex oculo-motor tracking tests various stress responses would occur such as blinks, eye closures, and increased heart rate. It was hypothesized that the frequency of blinks would increase over the course of each day's test administration and also that these blinks would impair the subject's ability to track the lines accurately and rapidly.

The possibility existed that the parafoveal left and right illumination conditions might affect scanning time differentially, i.e., because the scan is always from the left to the right, the parafoveal left illumination condition might cause the scanning speed to be faster (perhaps to try to avoid the side of the bright illumination) than the scanning speed performed under the parafoveal right condition. In the parafoveal right condition the direction of scan is toward the side of the brightly illuminated region; the subject may exhibit an avoidance type of response by slowing his average scan times in this direction.

Regarding the foveal and ambient illumination conditions, it was hypothesized that the foveal condition would yield more blinks and eye closures than would the ambient condition due to its "stressful" nature.

The pattern of lines used in this test was similar to the MacQuarrie "Visual Pursuit Test" (MacQuarrie, ref. 38). Tuckman (ref. 39) reports that the first (1925) edition of this test provided norms on approximately 1000 high school and college age subjects. A revised (1943) edition made percentile norms available for 1000 males and 1000 females all of whom were over 16 years old. In his test administration, Tuckman (Ibid.) administered the MacQuarrie Test for Mechanical Ability to 303 males and 334 females (ages 14 to 16 years) all of whom were enrolled in college preparatory classes. In the Manual of Directions for this test (ref. 38), norms for the Visual Pursuit Test are provided for various occupational groups including aircraft engineering draftsmen and aviation maintenance personnel. Advanced engineering draftsmen trainees (N = 23) scored in the 85th percentile on this test while 170 beginning draftsmen scored in the 82nd percentile.

Apparatus and Instructions: Each of the five visual tracking test patterns was photographically reproduced on a separate 14" x 14" cardboard. The outside dimensions of the enclosed rectangular pattern measured 12" x 7.25". The complexity of each card was different because of differences in individual line length and the number of line crossings. It was expected that these differences would become evident as inter-card score differences.

The subject was instructed to keep his eyes closed while the stimulus card was being inserted into the holder. He opened his eyes on signal and waited for the experimenter to call out the number one or ten indicating whether he was to begin at the top (and work down) or at the bottom (and work up). The subject then visually scanned the maze from left to right as rapidly as possible to determine the correct answer.

The instructions given to the subject on the first several administrations of this test were as follows:

> "This is a test for pursuit. Notice the numbers in the squares at the left, where the curved lines begin. When the experimenter says "Go", but not before, follow each line by eye from the square where it begins at the left to the square where it ends at the right and then immediately call out the letter. Go immediately to the next starting box and so on until you have completed all boxes."
>
> "Ready..."Go."
>
> "Stop, look away from the stimulus card and close your eyes."

The experimenter recorded the total administration time for each stimulus card as well as the sequence of letters called out. A total of five different stimulus card patterns were presented in random order each day.

6. <u>Visual Search Strategy Test</u>: (VSST)

It seemed to be of both practical as well as theoretical importance to know what kinds of eye movement search patterns and related ocular behavior occur when a bright beam of simulated solar radiation is present in various locations within one's field of view. (1) Does the subject try to avoid the bright beam? (2) Does he perform the stimulus search and identification as well under the bright light condition as under lower luminance "ambient" condition? (3) Does he develop consistent response patterns such as blinking or eye closures?

Visual search has been defined as a situation where the environment is fixed and the subject's eyes move by; in general, it can be said that when the subject is looking for something, his eyes move in a discontinuous fashion so that information is gathered from the visual environment in a succession of discrete fixations separated by rapid eye movements (Koestler and Jenkins, Ref. 40).

Meudell and Whiston (Ref. 41) have reported that when one stimulus variable (letter of the English alphabet) is used, the average search time is a linear function of the total number of targets on the display. They also determined that the ease of stimulus identification is correlated with the ease of letter localization.

Crovitz and Daves (Ref. 42) have shown that the initial direction of an eye movement following the offset of a tachistoscopically presented display correlated highly with the part of the display most accurately reported by the subject. When lines of letters are presented across the subject's visual field, accuracy of letter report has been found to depend upon the relative position that the letter occupies within the line and not its absolute retinal locus (Refs. 43 - 45).

Several interpretations have been made concerning searching behavior. Heron (Ref. 46) has proposed a cognitive scanning hypothesis where the subject scans the neural stimulus trace as he habitually reads, e.g., with English, a left to right scanning direction is used and the leftmost traces will be scanned more frequently than those on the right. If the stimuli are in the left half of his visual field the subject need only scan the left, whereas for the stimuli to the right of the fixation point the subject must scan left and back again. Thus the subject imposes his own response set in the form of left to right reporting in this free scan situation. Some evidence is available to support this theory. Bryden (Ref. 47) reports that when a horizontal row of stimulus letters is used, the subjects tend to report it from left to right. Ayres and Harcum (Ref. 48) found similar results using binary patterns. If the material is arranged in two rows, the top row is given first, from left to right, followed by the bottom (Refs. 46, 49, 50). Mewhort (Ref. 51) has found that subjects are most likely to use a fixed, left to right sequence order of report with letter sequences having a high degree of sequential redundancy than those with low redundancy. Bryden (Ref. 47) found that more letters were identified on the left no matter what order of report was used (left-right, right-left). Woodrow (Ref. 52) and Sperling (Ref. 53) have found that reading from left to right is the easiest and most accurate direction.

Wolford, Wessel, and Estes (Ref. 54) have proposed a serial processing model where elements of a display are scanned singly along some path with the process terminating when the signal element is located. Cohen and Meudell (Ref. 55) have stated that subjects use either an up-down and across (horizontally) strategy or a spiral strategy when viewing letters.

A study which is particularly relevant to the present investigation was performed by Purcell, Stewart, and Dember (Ref. 56). They found that target detectability will decrease as target-field luminance (30,40,50,60 ft-L) and viewing duration increases. Several working hypotheses are proposed from this literature review:

1. Search time will be shorter for stimuli which are located farther from the fixation point.

2. The general direction of scan will be from left to right.

3. Direction of initial eye movements should correlate highly with letter location.

4. Parafoveal stimulation will initially force the subject to scan in the opposite direction from the side illuminated.

5. On an average, scan times will be shorter for the ambient condition than the foveal condition.

Apparatus and Instructions: Visual scanning movements were monitored in two separate ways, by standard horizontal and vertical electrooculographic recordings (EOG-H and EOG-V, respectively) and also by an infrared corneal-scleral reflection technique using a Space Sciences, Inc. Model SGHV-2 eye movement device (EMD). The corneal reflection apparatus consisted of an Eye Point of Regard (EPR) system described in detail elsewhere (Ref. 57). In general, however, it used spectacle frames to align and support the infrared emitting sources and photocell receptors for both horizontal and vertical eye movements.

The head movement device (HMD) included an electromechanical X,Y coordinate sensor connected by a telescoping linkage to an anchor point on the stimulus panel. The nominal angular range of the HMD (Head Movement Device) is ±40 deg. horizontally and ±20 deg. vertically, with resolution of about ±1 deg. in either axis (Ref. 57).

The vertical and horizontal eye movement voltages were filtered, (λ = .016 sec.) to reduce AC noise. The usable angular range of the EMD is ±20 deg. horizontally and ±10 deg. vertically with accuracies of 1 deg. and 2 deg., respectively.

The EPR computer is a special purpose miniaturized analog computer which combines the horizontal and vertical eye and head movement rotation angles to yield the coordinates of the eye's line-of-sight upon the display.

The output of the EPR system was displayed on a storage CRT. By duplicating the card's stimulus pattern to scale on a transparent CRT mask, eye movements, blinks, and fixations could be viewed and photographed.

The visual stimuli used consisted of 25 letters of the English alphabet located on 2.5" centers in a 5 x 5 matrix which was centered upon a 14" x 14" cardboard. The inter-letter visual angle spacing has already been given in the Peripheral Response Time test description section. (See page 20)

Only fifteen of the total 25 possible letters (per stimulus card) were called out to the subject each day to help control for learning effects. The center letter was used as a "home" fixation position between trials, i.e., the subject fixated here after he had successfully located the letter called out but before the next letter was called out. The experimenter called out each of the 15 letters in random order without replacement each day for each of the five stimulus cards. The five cards were presented in random order each day.

Each of the black letters were of the same height (0.08") and maximum width (0.066"). At the 24" viewing distance the stroke width and line separation of each letter was equivalent to an acuity of 20:200 (Snellen notation). Since all letters were photographically reproduced, their contrast and reflection characteristics remained constant across all cards.

7. Hand Steadiness Test: (HST)

The ability of a person to accurately position a dial, counter or other adjustable control requires well developed eye-hand coordination and steadiness. This is also true in the weightless environment of space. In the absence of gravity - aboard an orbiting space station - the possibility exists that arm, hand, and shoulder muscles which on earth are used to counteract the force of gravity may exert a small "counter" force toward the person's head until they become "habituated" to the weightless state. A test of this hypothesis in space could lead to the development of new understandings of the human muscular system development and responses to gravity. The present hand steadiness test may provide one means of testing this hypothesis.

Accurate eye-hand coordination also involves a number of other factors. Of particular interest here is the effect of simulated solar illumination upon hand steadiness. Is hand steadiness affected when the steadiness test device is viewed against a much brighter background?

Another important factor related to eye-hand coordination is fatigue. It might be expected that as a precision hand steadiness test proceeds in a one-g environment, the number of stylus-hole contacts will increase due to increased muscular tremor (sometimes called tetanus). An interesting question can be raised about the development of muscular fatigue in the zero-g environment. Will a prolonged test of hand steadiness in the weightless space environment induce the same kind of muscular fatigue as is found on earth? And, will the frequency and amplitude characteristics of this tremor, if any occur, be similar to or different from that found on earth?

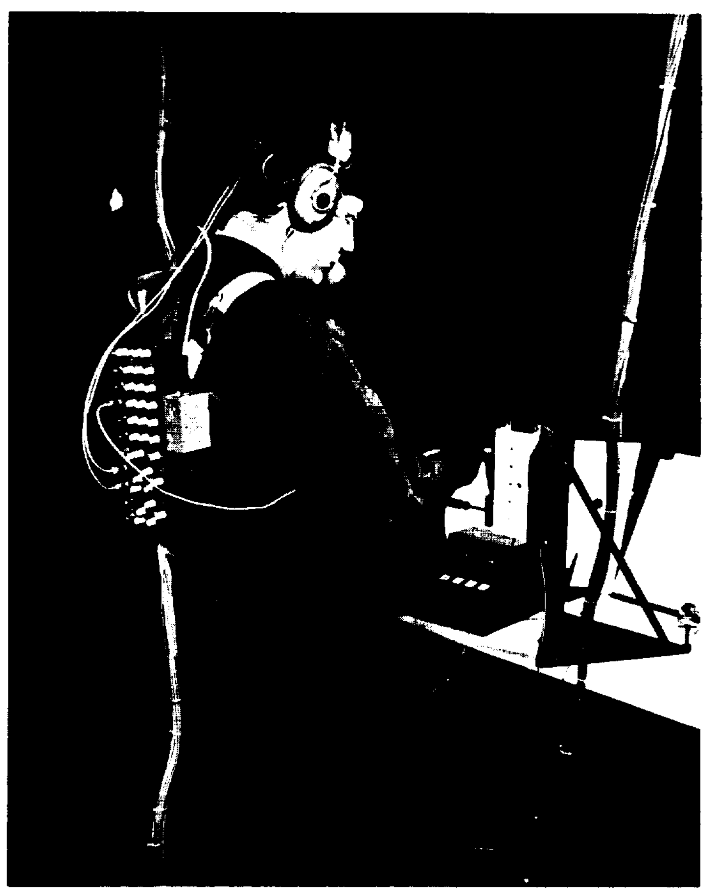
A serious effort must be made to keep the person's interest and motivation in the hand steadiness task as high and as stable as possible. Disinterest in this kind of task can contribute to lower test scores over time. Our previous pilot studies have shown that periodic subject debriefings, a relatively high hourly rate of pay, and periodic, verbal feedback on accuracy of performance are effective techniques in maintaining the subject's motivation in this task.

Another important factor in tests of hand steadiness is body stance (posture). For a typical standing test, maximum body stability is obtained by positioning the feet approximately 90° to one another in a "boxing" or "fencing" position with the extension of the midline through the leading foot passing through the heel of the back foot; both feet should be about 12" apart. The upper and lower arm position of the arm holding the stylus is important as well. In the present investigation the upper arm was vertical and rested against the chest, while the forearm was held horizontally with the palm up. Thus, some stylus stability was gained by contact of the entire upper arm with the trunk of the body.

Still another factor has been found to be important in a hand steadiness test, viz., whether or not some form of accuracy feedback is provided. In the present investigation, a very small, dim but visible spark was produced when the tip of the stylus touched the edge of the testing hole. No other feedback cues were present.

Apparatus and Instructions: The apparatus consisted of a five-hole test plate, a stylus, and experimenter control panel. The hand steadiness test plate face measured 3" x 5" and was mounted upon a support stand which allowed it to be oriented both horizontally and vertically. The plate was also electrically separated lengthwise into two equal sections. Thus, stylus-hole edge contacts could be recorded for each half of each hole separately. Figure 12 shows a subject performing this test under ambient illumination conditions.

Figure 12



The test hole diameters were: 0.265", 0.212", 0.163", 0.152", and 0.114" in this order. The metal stylus' tip diameter was 0.047" and was 4" long. It was inserted into a 5" long insulated handle which was connected to the test plate by a long flexible wire.

The center of the hand steadiness test plate was located 48" above the floor and on a line between the subject's eyes and the central, 14" x 14" work panel. The test plate face luminance was approximately 150 ft-L for all three beam positions. Each of the three sunlight conditions acted as intensely illuminated glare sources which were seen behind or to each side of the test plate.

The experimenter's control panel contained three, 1/100th second accuracy timing clocks and appropriate circuitry. One clock measured total elapsed test time per hole (= 30 seconds), the second clock measured total contact time of the stylus with one-half of the hole being tested. A third clock measured total contact time of the stylus with the opposite side of the hole.

The hand steadiness test was administered twice per day to each subject, once just after having entered the work area and again, just before leaving it about two hours later. During each test administration the subject completed a total of ten trials (five holes and two hands) in a random order. Each of the ten trials lasted 30 seconds and was separated from the following trial by about 15 seconds. In addition, a one minute practice session was given before each administration. Thus, the total time required to administer the hand steadiness test was approximately 8.5 minutes. In addition, the test plate was oriented either horizontally or vertically for both administrations each day.

The subject stood facing the test plate with his toes touching taped areas on the floor 15" away from the face of the test plate. His feet were approximately 6" apart. A line connecting the toe of each foot was parallel with the face of the test plate. This foot position was chosen, rather than the boxing position because it more closely approximates the foot position of a crewman directly facing a counter top work area.

The following instructions were read to the subject on the first several administrations of this test:

> "You are about to take a hand steadiness test. Before you is a rectangular plate with five holes arranged from largest to smallest along the length of the plate; an orange handled stylus is connected to the plate by a wire. Your task is to hold the stylus within a specified hole with the specified hand as steadily as you can for 30 seconds. You are asked to hold the stylus by the orange handle and not to touch any part of the metal stylus rod. Please keep your palm facing upward when holding the stylus within the hole. You are to stand facing the plate with your feet in the foot placement areas marked on the floor.

"Each of the five holes will be referred to by a number; the largest hole is number 1, the next hole is number 2, and so on with the smallest hole being number 5. Before each 30 second test period you will be instructed within which hole and with which hand to hold the stylus. When you have the stylus within the hole and are ready for the test to begin, say 'Ready'; at the end of the 30 seconds I will say 'OK, come out'. You will have a 15 second rest before I will instruct you on the next hole and hand to be tested.

"Do you have any questions?

"You will now have one minute to practice before the test begins."

8. Body Balance Battery: (BBB)

In this section of the experiment a battery of body balance tests was used to measure static and dynamic postural equilibrium and steadiness. The test battery incorporated features of the quantitative ataxia test developed by Graybiel and Fregley (Ref. 58). Applications of this type of test extend back to 1853 when Romberg developed tests for various nervous diseases (Ref. 59). In 1962 similar tests were administered to NASA astronauts Glenn and Carpenter before and after their orbital flights to measure the effect of short duration space flight on body balance.

Numerous studies have used "rail" tests to measure ataxia and postural equilibrium (Refs. 60 - 72). Fregley et al.(Ref. 72) used the ataxia rail test to evaluate the nonvestibular contributions to postural equilibrium and to establish a hierarchical relation for these contributions.

Dickinson and Leonard (Ref. 70) found that peripheral vision is important to static postural equilibrium because it provides information about body position relative to itself. Dickinson (Ref. 71) evaluated the effect of blindfold, full-sight, and minimal vision cue conditions on rail walking performance. He found that, to maintain one's body balance, subjects rely heavily on any available visual information, poor as it may be. In order to improve body balance capability in environments which provide only minimal visual cues, subjects make use of vestibular, kinesthetic and proprioceptive sensory cues. These studies suggest that body balance may be adversely affected by the presence of a bright image in the periphery of one's visual field while the remainder of the visual field is dark due to an overall reduction of visual cues.

Guedry et al (Ref. 67), Newsom et al (Ref. 68) and Graybiel et al (Ref. 69) tested the balance of subjects in a rotating environment. Their findings support their contention that man can adapt to such an environment. In all cases the subject's performance on various body balance tests reached pre-rotation baseline levels in a relatively short period of time in this environment. However, a significant decrement in body balance occurred just after rotation began and also just after it ceased. In addition, Newsome et al (Ref. 68) found that subjects confined to bunks during rotation did not show any post-rotation decrement. One explanation for this is that the non-confined subjects learned to make corrective balance responses to rotation while the subjects who remained in their bunks during rotation were not able to develop appropriate compensatory responses. Thus, they did not have to readapt to the non-rotating environment.

Apparatus and Instructions: The primary apparatus for the Body Balance Battery was a 2" x 4" rail mounted on a 10' long, stable base. The subject balanced upon the 2" side. The rail was placed approximately parallel to and 2' away from a wall on the subject's right side.

The Body Balance Battery consisted of ten tests which can be grouped into four categories: (a) Romberg on the Floor, (b) Romberg on the Rail, (c) One Leg Rail Balance, and (d) Rail Walk. In addition, each category had two parts: eyes open (EO) and eyes closed (EC).

The subjects were required to keep their arms folded across their chest, and to face away from the solar simulator for all tests. Both right and left legs were tested in all tests except the rail walk test.

(a) The Romberg on the Floor Test is also known as the Sharpened Romberg Test. Hereafter it will be designated by the initials SRT. This test required that the subject stand heel-to-toe with his right foot in front. The 60-second test was administered with the subject standing approximately 5' from and facing one corner of the work area.

(b) For the Romberg on Rail Test (RORT) the subject assumed the heel-to-toe (Romberg) position upon the rail. He was allowed time to establish his balance after which the 60 second, eyes open trial commenced. For the eyes closed portion of this test, the subject established his balance and then closed his eyes. This test lasted 30 seconds. Figure 13 shows a subject performing this test.

(c) The One Leg Rail Balance Test (OLRB) required the subject to stand with one foot on the rail with his toe at the start line. After he had established his balance, the subject removed his other foot from the floor and the 60 second trial was begun. The eyes closed test lasted 30 seconds.

Figure 13

(d) The Rail Walk Test (RWT) required the subject to assume the Sharpened Romberg position on the rail with his right foot at the start line (see Fig. 13). Timing started when he began walking and was terminated when he fell off or reached the end of the rail. The maximum rail walk distance was 8'. The eyes closed portion of this test differed only in that the subject closed his eyes at the start of the rail walk.

The instructions were as follows:

"You are about to take a battery of body balance tests. Each test will be explained prior to its administration. Each test will start when you have achieved the desired position, and will stop when you can no longer maintain it or have maintained it for the specified time. You are asked to call out, in your microphone, the name of each test and when you start and stop."

Each test was then explained by giving details similar to those presented above for each of the tests. The subject was asked if he understood what he was to do. If he did not, applicable parts of the instructions were read again until he understood them.

9. Precision Eye-Hand Coordination: (DT)

As was mentioned in the hand steadiness test description, the ability to make rapid and accurate hand movements is important in a number of operations in the space environment. Great accuracy is required to input numbers into the on-board navigation computer; eye-hand coordination is essential to this function. Speed and accuracy is also essential if the astronaut should detect that a warning light has come on (e.g., during left off) to which he must take some corrective action (e.g., press the abort trigger button). Many other examples could be mentioned where the eye and hand must work in coordination. In the present investigation we were interested in relating each of the illumination conditions to performance on a precision, eye-hand coordination task.

Tests of eye-hand coordination have been studied in a variety of contexts such as accuracy (Refs. 74 - 77), direction and length of the stimulus path (Ref. 78), and target luminance (Ref. 79). In Wheelus' et al study (Ref. 79) it was found that saccadic eye movements decreased in latency as target luminance increased over a 3.5 log range. No studies could be found, however, which investigated the speed and accuracy of a dotting test in a visual environment similar to the one studied here.

In the present study, the effect(s) of the bright beam of sunlight imaged within various parts of the subject's field of view was related to the subject's ability to place pencil dots within many small circles located upon the foveal stimulus card.

Apparatus and Instructions. A pattern similar to that used in the dotting subtest of the MacQuarrie Mechanical Ability Test (Ref. 38) was used in the present investigation. This black line pattern of 100 circles and connecting lines was photographically reproduced on a 14" x 14" cardboard having the same diffuse white background as the other 14" x 14" stimulus cards. It could be oriented into each of four positions. Since there were two ends to the continuous line connecting the circles, a total of eight possible starting positions were available. The starting position was chosen at random each day with the restriction that one stimulus card orientation had to be a vertical line orientation and the second a horizontal line orientation. The center of the dotting pattern was 24 inches from the subject's eyes. Figure 14 shows the Precision Eye-Hand Coordination test in a horizontal orientation.

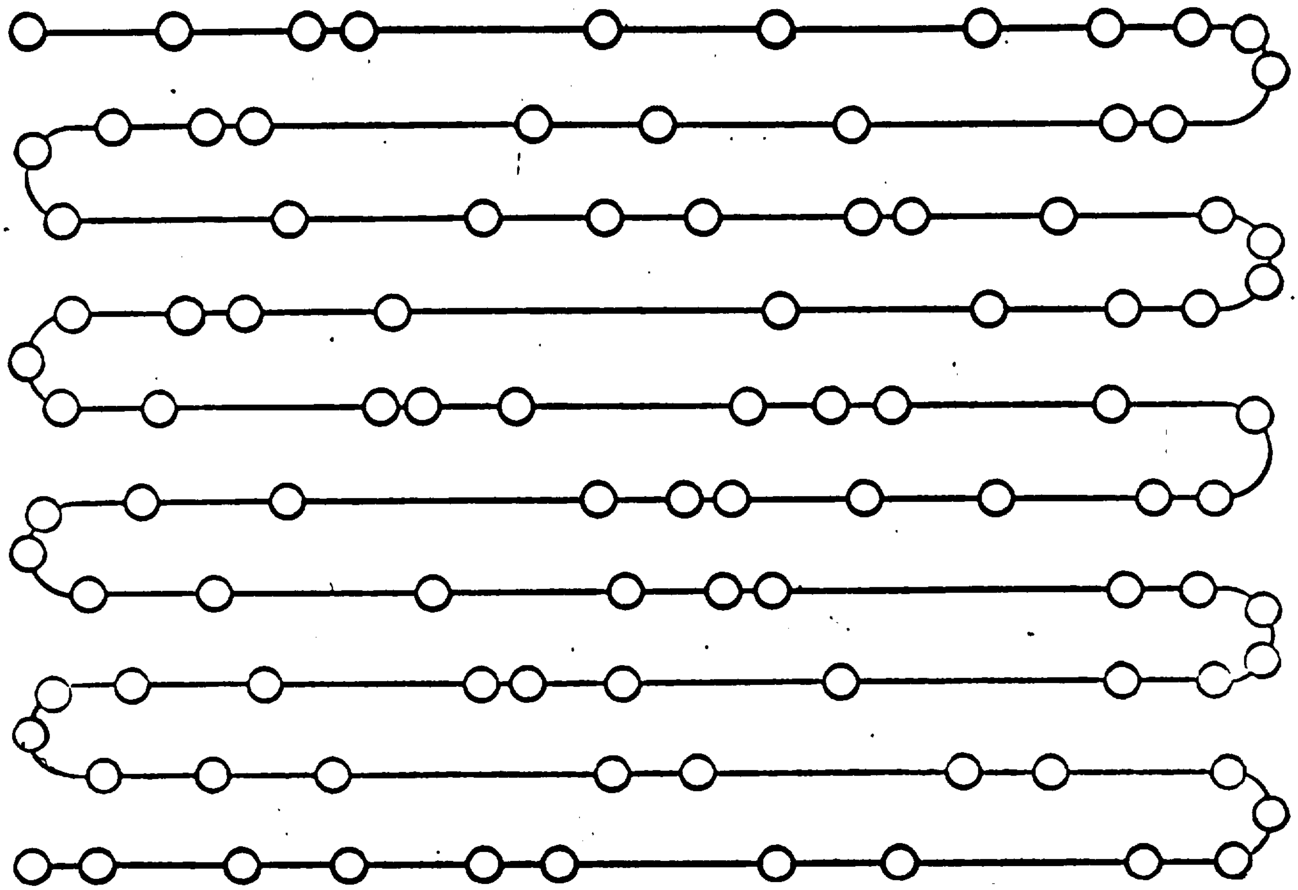


Figure 14

Scoring was done with the aid of a clear plastic overlay upon which the subject made his responses with a felt tip pen. Each day's results were scored and then photocopied for later analysis. The results were scored both for speed and accuracy. Speed was determined by counting the number of dot-within-circle responses made in the fixed 30 second trial period. Accuracy was determined by counting the number of dots which were placed outside the circles as well as where they were relative to the circle's center.

This subtest of the MacQuarrie Mechanical Ability Test has been administered to a sample of 1,000 males and 1,000 females of high school age (Ref. 39). This test-retest administration yielded a correlation of 0.90. However, a study which related scores on this test with the results from group mental tests found a correlation of only 0.20; the reliability of this subtest was found to be 0.74 using three groups of subjects with 35, 80, and 250 cases. When the scores from this subtest were compared with teacher ratings on mechanical ability, the correlation was marginal (0.48).

Based upon what is already known about the effects of high luminance upon visual performance the following working hypotheses were formulated: More dotting errors (dots placed outside the circle) will be made near the side of each circle nearest the sunlight beam's image position for the parafoveal left and the parafoveal right illumination conditions and less dotting errors will be made under the ambient illumination than under the foveal illumination condition.

The subject's instructions were as follows:

> "This is a test of precision eye-hand coordination. When the experimenter says 'go', but not before, you are to put one dot inside each circle as fast as you can. Follow the dots in order and be sure to use the starting position given by the experimenter. The dots must be clearly within the circles and only one dot will be counted for any circle. When the experimenter tells you the starting position you should place your hand on that position and say 'ready.' The experimenter will then tell you to 'go.'
>
> "When the experimenter says 'stop' you should sit erect in your chair and close your eyes until told to do otherwise.
>
> "Are you ready? Do you understand these instructions? Your starting position is... 'Go'."

10. <u>Ames Crew Evaluator</u>: (ACE)

A continuing effort has been made to develop quantitative and qualitative tests of higher mental function, reasoning, and decision making capabilities. With the proper choice of tests of mental function such a test could be useful on board long duration space missions as well as in other environments. One device of this type is the "Logical Inference Tester" (LOGIT) (Ref. 80). It was designed for use by the same subject(s) over long periods of time in confinement situations. Its internal logic permits sufficient randomization of the stimuli presented to control for learning. The LOGIT's response panel consists of 20 numbered, internally lit, buttons. The subject's task is to learn, with a minimum of trials, the correct order in which the 20 buttons should be pressed. Presumably, this is learned through a combination of rote memory and deductive logic in accordance with a simple principle. The LOGIT is described as a test of "higher mental processes, including reasoning, memory and decision skills." (Ref. 80, pg. 1-6).

The LOGIT tester was used by Parker (Refs. 81-82) in validation studies for the U. S. Navy. In one test the face of the response panel was intermittently illuminated at 12 pulses per second by a Strobotac so as to produce a "distraction." In addition, the subject's ECG and GSR was monitored. Although

Parker (Ref. 82) did not find significant changes in either of the two subject's problem solving ability due to the flashing light, he did find that the time required to complete the problems was increased appreciably. In other words, the subjects seemed to optimize accuracy at the expense of speed.

A cognitive, short-term memory test developed at Ames Research Center was used in the present investigation. It is called the Ames Crew Evaluator (ACE) and consists of a preprogrammed, stimulus-response device which determines how well a subject can respond to periodically presented symbols by pressing one of four keys with a corresponding symbol. A one plane, visual display presents the symbols. The ACE response console is shown in Fig. 15. A red (incorrect) and green (correct) response feedback light is also located on the console (seen on each side of the square screen in Fig. 15.

Figure 15

Order of symbol presentation was randomized. A symbol appeared approximately every second. Table 3 presents the testing schedule used on even numbered test days. This schedule was alternated subject for subject on odd numbered test days. The no delay mode indicates that the subject pressed the appropriate response key immediately after a symbol had appeared on the display screen.

Table 3

Test Schedule for the ACE

Subject 1	Subject 2
Practice 1 minute no delay	Practice 1 minute, 2 symbol delay
Test 1 3 minute no delay	Test 1 3 minute 2 symbol delay
Test 2 3 minute 2 symbol delay	Test 2 3 minute no delay
Test 3 3 minute no delay	Test 3 3 minute 2 symbol delay
Test 4 3 minute 2 symbol delay	Test 4 3 minute no delay

The two-symbol delay mode indicates that the subject had to respond (by pressing the appropriate key) to the screen symbol which had appeared two response intervals previously. Therefore, the subject had to remember what the two intervening symbols were in order to respond to them correctly.

The associated electronic circuitry and logic also provided for measurement and recording of the subject's reponse time to each symbol, the number of times he failed to respond in time, and the correctness or incorrectness of his response.

A total of 180 trials were presented during each three minute test and 60 during the one minute practice. Thus, a total of 780 trials per day were administered for a total of 10,140 trials for subject RM and 9360 for subject JD.

Subjects:

Two male volunteer, college students (ages 19 and 24 years) took part in the investigation. Each passed an extensive battery of visual, body balance and stability, and other tests. Results from the vision tests indicated that subject JD had 20:20 uncorrected near and far acuity using four different tests. His cycloplegic refraction was (OD = plano +0.25 x 180°) (OS = -0.50 +0.50 x 10°). He possessed normal color vision as measured by the Ishihara color plates, normal accommodative range (OD = 7 cm) (OS = 10 cm), normal and full visual fields, and normal intraocular pressure. His fundus appeared normal in every respect. Results from the Ortho-rater vertical phoria test were (near = 0.5 LH) (far = 0.17 LH); the horizontal phoria test results were (near = -7.5) (far = -2.66). His Ortho-rater stereopsis acuity was 19" arc angle.

The results of the vision tests for subject RM indicated that he had 20:18 uncorrected far and 20:15 uncorrected near acuity in both eyes using four different tests. His cycloplegic refraction was (OD = plano + 0.25) (OS = plano + 0.50). He possessed normal color vision as measured by the Ishihara color plates, an accommodative range of from (OD = 8.5 cm) (OS = 8.5 cm) near point to infinity, full and normal visual fields, and normal intraocular pressure. A fundus exam indicated no apparent anomalies. Results from the Ortho-rater vertical phoria test were (near = 0.5 LH) (far = 0.17 RH); the horizontal phoria test results were (near =-3.0) (far =-5.66). His Ortho-rater stereopsis acuity was 9.7" arc angle. Table 4 summarizes the results from the other tests which were administered.

Table 4

Other Test Results and Comments

Test	Subject	
	JD	RM
Blood Pressure (date)	118/75 (7-30-70) 112/84 (8-10) 120/68 (8-17)	115/78 (8-4-70) 112/80 (8-10) 116/88 (8-27)
Munsell iris color	5G 5/1 (grey green)	5 YR 4/4 (yellow brown)
General state of health	Excellent	Very good
Diabetes (self or in family)	No	Yes (mother)
Symbolic Reasoning Score (Psychol. Services Inc.)	40th. centile	87th centile
Space Visualization (Psychol. Services Inc.)	81st centile	45th centile

RESULTS

The results are presented by test. The following symbols are used to denote the illumination condition and test day of the week: A = Ambient, F = Foveal (center panel illuminated), PF-L = parafoveal left panel illuminated, PF-R = parafoveal right panel illuminated, M = Monday, Tu = Tuesday, W = Wednesday, Th = Thursday, F = Friday. The calendar date is given, to show the day each subject was tested over several weeks.

1. Visual Acuity Test Results:

All three sunlight conditions enhanced both subject's visual acuity compared to the ambient illumination. Subject JD's acuity was between 20:25 and 20:30 in both eyes under ambient illumination while subject RM's was better than 20:25 (equivalent to a visual angle separation of 1' 15" arc). Data given in Table 5 indicates that, for the ambient illumination , subject JD missed approximately the same percentage of test patterns for each of the three gap sizes while subject RM missed a larger percentage of the smaller gap sizes in each eye.

Table 5

Percentage of Acuity Gaps Missed
Under Ambient Illumination

		Eye			
		Left		Right	
		JD	RM	JD	RM
Acuity Level	20:33	44	0	26.6	20
	20:30	40	0	30	20
	20:25	36	30	29	30

The results of the physiological monitoring conducted during the visual acuity test are presented in Table 6 and 7. Slightly slower heart rates occurred under the sunlight conditions than under the ambient illumination for both subjects. Blinks were not analyzed for this portion of the test record.

Note: All of the remaining Tables and Figures are located at the end of the report in Appendix A.

2. Visual Fixation Steadiness Test Results:

The EOG recordings were used to determine visual fixation steadiness. Vertical EOG recordings were accurate to approximately 1.5° arc and horizontal recordings to 2° arc resolution according to comparisons made both before and after each day's testing with an EOG calibration pattern. Because the head and body were free to move in space, these EOG recordings indicate eyeglobe rotation relative to the subject's skull. Figure 16 presents a typical one minute sample of the vertical (left channel) and horizontal (right channel) eye movements. Also shown are one second timing marks (right edge) and visual angle calibrations for each eye movement direction. The results given in Table 8 are for the first and last 30-second segment of the five minute-long test. Figure 16 Table 8

These data indicate that subject JD made larger involuntary horizontal eye movements and smaller involuntary vertical eye movements under the sunlight condition while subject RM's involuntary horizontal <u>and</u> vertical eye movements were larger under the sunlight conditions than under the ambient illumination condition for both 30 second periods.

For almost all of the data shown, the eyeglobe rotation within the skull had a frequency component of from 3 to 8 hz with horizontal movements ranging from 1° to 3° arc and with vertical movements ranging from less than 1° to 3° arc. Considering that the subject stood with no body support (other than the floor), these data indicate relatively good visual fixation stability. These data will be of interest when compared with data obtained from later investigations utilizing a constantly moving sunlight beam.

A blink serves three primary purposes: to keep the cornea moist, to wash away foreign particles, and to reduce the retinal illumination level temporarily. The latter response can be thought of as an avoidance response to bright visual scenes.

The mean number of blinks which occurred during the first and last 30 seconds of the visual fixation steadiness test was determined. For the ambient illumination condition subject JD blinked 19 times and 28 times during the first and last measurement periods, respectively. He blinked an average of 8 and 46 times for these same periods under the sunlight conditions. Thus, the brightly illuminated panels - situated beneath his horizontal line of sight - produced a greater increase in blink rate in the last 30 second measurement period than did the ambient illumination condition. This is shown as percentage of total blinks in Table 9. Table 9

Under the ambient illumination condition subject RM blinked an average of 0 and 9 times during the first and last 30 second long measurement period, respectively. He blinked an average of 9 and 26 times for these same measurement periods under the sunlight conditions. Table 10 presents these data as percentage of total blinks which occurred by experimental condition. Table 10

Data given in Table 11 show that mean heart rate decreased slightly under the sunlight illumination conditions compared to the ambient illumination condition for subject JD. This decrease was not statistically significant. Mean heart rate remained the same for subject RM for these two conditions. The total number of blinks made by each subject each day is also given in Table 11. Subject JD blinked less and subject RM blinked more under the sunlight illumination condition. Table 11

3. <u>Peripheral Response Time Test Results:</u>

Table 12 and 13 present the mean response times and standard deviations for both subjects; Figure 17 through 20 present these results graphically. There was a statistically significant increase in response time for those test lights located on the side of the subject's visual field where the solar beam was imaged. When the bright beam was imaged upon the center (foveal) panel the curve which showed response time as a function of test light location was flatter. The extremely long response times found under the PF-R illumination condition for the 30^{o}_{R} and 60^{o}_{R} stimulus lights are due to the fact that the sunlight fell directly upon the red plastic lens caps making the onset and offset almost unperceptible. Table 12 - 13 Figure 17 - 20

Table 14 presents an analysis of the location at which errors were made averaged across both subjects. An error was scored when the test light was not detected within 4 seconds. Both PF-L and PF-R illumination conditions produced more errors on the side at which the sunlight beam was imaged. Response time increased under the foveal condition to test lights located on the right-hand side; more errors were also made on this side. A chi-square analysis was performed on the error distribution, with errors pooled for the 90^{o}, 60^{o}, and 30^{o} stimulus positions on the left versus the 90^{o}, 60^{o}, and 30^{o} stimulus positions on the right. In both the PF-L and PF-R conditions, the number of errors was significantly ($p = .01$) greater on the side at which the beam was directed. Table 14

Subject JD's mean heart rate under ambient illumination was 79.2 (S.D. = 5.3) and 78.8 (S.D. = 4.2) beats per minute under the sunlight condition. Subject RM's mean heart rate under ambient illumination was 84.1 (S.D. = 6.2) and 82.1 (S.D. = 5.4) beats per minute under the sunlight condition. These differences were not statistically significant. Mean heart rate tended to increase by about 5 beats per minute during the last half of this 15 minute-long test.

4. Visual Tracking Test Results (Straight Lines):

This was the only test which was positioned flat upon the subject's work table between himself and the foveal panel. Therefore, both the foveal and the parafoveal right illumination conditions reflected sunlight down upon the test. The parafoveal left illumination condition produced a greater variability in illumination level due to the various shadows which were discussed in the method section.

An analysis of the two test forms showed them to be equivalent in terms of total line length, number of right- and left-hand 90° corners, and number of times each line crossed another line. In fact, form A contained 3 lines which were identical to those found in form B. The mean visual scan time for the central 10 lines by illumination condition is given in Table 15. For subject JD, the mean scan time under ambient illumination was significantly longer than it was for the F, PF-L and PF-R conditions. None of these comparisons was significantly different for subject RM, however. Table 15

When total scan time is plotted for each day for each subject over the entire experiment the sunlight conditions were found to reduce scan time by approximately 10 percent for both subjects. Mean heart rate and total number of blinks during this entire test is given in Table 16. Table 16

5. Visual Tracking Test Results (Curved Lines):

In order to determine whether or not learning could account for any of the present results, mean scan time per card was compared over the entire experiment. Subject JD's data indicated that learning had occurred during the first three days of testing under the ambient illumination, however, no consistent mean scan time trends were found thereafter. Subject RM's data indicated no learning effect at all.

The mean scan time results and total length of all ten lines per stimulus card are given in Table 17 and 18. As expected, a statistically significant ($p < .05$) correlation was found between total line length and mean scan time per card under all four illumination conditions. Table 17 - 18

The presence of sunlight enhanced the subject's ability to scan this maze of overlapping curved lines in most of the trials.

The first hypothesis raised was that the mean scan time would be faster for the PF-L than the PF-R illumination condition. The data given in Table 17 and 18 show that this occurred for 3 of the 5 stimulus cards for subject JD and for 4 of the 5 stimulus cards for subject RM. The largest difference in mean scan time, comparing across all four illumination conditions, was 18.1 seconds for card 3 for subject JD and 14.7 seconds for card 3 for subject RM.

The second hypothesis raised was that the subject's oculo-motor system would be fatigued by the five consecutive stimulus card presentations each day and that this would be shown by an increased blink rate, more eye closures, and/or an accelerated heart rate over the course of each day's testing. An eye closure is arbitrarily defined as any vertical EOG deflection which remained maximally deflected for 0.25 or more seconds. An analysis of these responses (presented in Table 19) did not support this hypothesis.

Table 19

The third hypothesis raised was that the foveal illumination condition would produce more blinks than would the ambient illumination condition. Table 20 presents these data. A statistical test of the differences between these means indicated support for this hypothesis for subject JD but not for subject RM. The minimum number of blinks occurred under the ambient illumination condition for both subjects.

Table 20

6. Visual Search Strategy Test Results:

These results were analyzed in relation to each of the four hypotheses discussed on pages 24 and 25 of the method section. Each of the 15 letters per stimulus card chosen for presentation each day were drawn at random without replacement and the five stimulus cards were also presented in a random order each day. Nevertheless, the possibility remained that the subjects could have memorized the letter patterns on some or all of the five stimulus cards. In order to find out whether learning may have occurred (as indicated by decreased visual search time per letter per card over time), six letters chosen at random from each of the 5 cards were analyzed. No learning effect was found for these six letters for either subject. Visual search times ranged from 1.1 to 14.5 seconds for subject JD and from 1.3 to 23.4 seconds for subject RM.

Regarding the first hypothesis raised, viz., that search time will be shorter when searching for letters located farther from the fixation position on the central panel, the data presented in Table 21 for subject RM for the ambient illumination condition support this hypothesis while data for each of the three sunlight conditions do not. No clear-cut trend is found in any of the data for subject JD with which to support this hypothesis. Subject JD was both faster by about 1 second and more consistent in the range of his mean search times than was subject RM for the majority of cases within each of the four illumination conditions.

Table 21

The second hypothesis was that the general eye-scan direction will be from left to right. Data with which to test this hypothesis came from both the EOG records and, for the ambient illumination condition, from the infra-red eye point of regard system, storage CRT and polaroid camera.

The EOG data were analyzed for the frequency of occurrence of eye movements from the center fixation point into each of four stimulus card quadrants. These data were then combined to show eye movements into either the right- or left-hand halfs and into the top and bottom halfs of each card. These data are presented in Table 22. Table 23 presents the mean visual search times for letters within each half of the stimulus card. The results of various t tests are given in the footnote. The only statistically significant ($p = .05$) right versus left visual search data analysis was under the ambient illumination condition for subject RM. These equivocal findings make it impossible to accept or reject this hypothesis.

Table 22

Table 23

More eye movements were found in the left half than in the right half of the stimulus card for the F, PF-L, and PF-R conditions for subject RM but did not occur for any of the four illumination conditions for subject JD.

Table 22 shows that both subjects made more eye movements toward the bottom of the stimulus card than toward any other direction. Subject JD looked least at the top half of the card for all illumination conditions except PF-R; subject RM looked least at the right half of the card for all illumination conditions except F. These data are considered as individual response biases.

Because the data of Table 22 represent only initial direction of the eye's movement from the central fixation point, the photographs containing the entire scan pattern was analyzed to further confirm or deny the second hypothesis. The polaroid photographs which were obtained were placed into similar scan pattern groups and then counted. The results of this analysis are presented in Figure 21.

Figure 21

Results presented in Table 22 can also be related to the third hypothesis which states that parafoveal illumination will <u>initially</u> force the subject to scan toward the opposite side of the stimulus card from the side nearest the sunlight illumination. This hypothesis was raised because of the possibility that each of the PF illumination conditions would act as an aversive stimuli to which the subject would respond by scanning in the opposite direction as much as possible. Although this occurred for the PF-L condition for subject JD and for the PF-R condition for subject RM it did not occur for the opposite PF illumination conditions for either subject. Again, these equivocal findings make it impossible to either support or reject this hypothesis.

The results from Table 22 and 23 can be compared for each subject for the number of initial eye movements and the mean visual search time for letters located in the right- and left-hand halfs of the stimulus card under the two PF illumination conditions. It is interesting that both subjects made more initial eye movements toward the same half of the stimulus card under either PF illumination condition but that they took less search time to locate the letter on that same side of the card, i.e., they made more initial eye movements, faster on one side of the stimulus card than on the other regardless of which side the sunlight was imaged. These data do not support hypothesis 3.

The fourth hypothesis was that search times will be shorter for the ambient than for the F illumination condition. Data in Table 24 show that this was not the case for either subject. Table 24

An analysis of blink rate indicated that there were no significant differences between any of the four illumination conditions for either subject. Subject JD blinked an average of 76 times (S.D. = 27.5) per day and subject RM, 48 times (S.D. = 19) per day during the Visual Search Strategy Test.

7. Hand Steadiness Test Results:

Results from this test are presented in Figure 22 through 29. Total error scores in these bar graphs indicate total stylus contact time upon each side of the test hole for each illumination condition and subject. For both the horizontal and vertical test plate orientations use of the smallest hole produced larger errors than did the use of the four larger holes. In addition, for the smallest hole in the vertical panel orientation (comparing right and left side error), total error was greater on the hole's right side than the left for both subjects under both illumination conditions. This suggests that the smallest hole is best for discriminating lateral hand sway. Data for the horizontal plate orientation (comparing top and bottom error) do not show a particular hole size to be particularly discriminating for vertical hand sway. Figure 22 - 29

Neglecting the side of the hole contacted, there is no significant difference between total error from either the horizontal versus the vertical panel orientations or from the right versus the left hand of either subject.

Table 25 and 26 present the mean heart rate and total blink data for the hand steadiness test. These data show that mean heart rate drops significantly from the first test administration to the second under both types of illumination (ambient, sunlight) for both subjects. Table 25 - 26

8. Body Balance Test Results:

The results from this test are presented in Table 27 and 28. None of the ambient versus sunlight comparisons was statistically significant.

Table 27 - 28

The present body balance tests were not expected to show statistically significant differences between the various illumination conditions because in no case did the light sources appear to move. The subject knew the location of the sunlight beam at all times and could, in fact, use this knowledge to help stabilize himself within the work area. The present findings are of value, nevertheless, as comparison data for later studies in which the sunlight beam will be made to pass through the work area periodically.

Mean heart rate data for each of the ten body balance tests are presented in Table 29 and 30 for subject JD and RM, respectively.

Table 29 - 30

9. Precision Eye-Hand Coordination Test Results:

The results of this test are presented in Table 31 and 32. The number of responses (dots) attempted is an indication of both the subject's motivation and speed of response. The proportion of the total number of dots placed within the circles and the number of dots placed outside the circles (errors) is an indication of his accuracy. The number of correct responses was obtained by subtracting the number of errors from the number attempted. The location of each dot with respect to the circle's center was also determined in order to see what influence the two PF sunlight image positions might have upon eye-hand coordination accuracy.

Table 31 - 32

It was hypothesized that both speed and accuracy would be systematically influenced by the location of the sunlight beam. Comparing the results from the three sunlight conditions, both subjects attempted fewer and got fewer correct when the foveal panel was illuminated.

Table 32 presents an analysis of the right to left and left to right eye-hand movements which occurred. Both subjects attempted more under all four illumination conditions when their eye-hand movement was from left to right than from right to left. Subject JD attempted most under the F and subject RM attempted most under the PF-L illumination condition. Approximately the same percentage of errors were made in either direction of eye-hand movement. The highest percentage of errors were made under the ambient illumination condition by both subjects regardless of the direction of eye-hand movement.

Table 32

10. Ames Crew Evaluator Test Results:

Results from this test are presented in Figure 30 through 33. In these graphs the ordinate, labeled Score, is the total number of correct responses made in two separate test administrations each day with a maximum of 360 possible correct. The abcissa gives the test day. The illumination condition corresponding to each day is given below the abcissa. The solid vertical line indicates the end of training and the beginning of the experimental data collection. In addition, the letter symbols which accompany each test day indicate the illumination condition. Numbers by each data point indicate the total number of errors made.

Figure 30 - 33

As was expected, the training portion of the zero delay test data showed a more rapid rise (steeper slope) than it did for the two symbol delay test. No consistent effect was observed for any of the three sunlight conditions.

DISCUSSION AND CONCLUSIONS

Because all overhead (ambient) lights were extinguished during all of the sunlight conditions most of the work area was in relative darkness. This fact seemed to make more difference on the various body balance scores than the fact of having a fixed bright beam of sunlight present or not. This finding emphasizes the great importance of providing adequate interior ambient illumination aboard the space station. Soviet investigators (Ref. 9) have suggested that the ambient luminance in the space vehicle's work areas should be about 3 to 4 ft-L (i.e., 10 - 15 nit) and that emergency operations can be carried out under luminances as low as 1.4 ft-L (0.5 nit). They also suggest that the luminance of the cabin be increased to from 5.7 to 14 ft-L (20 to 50 nit) during orbital insertion. Another source (Ref. 83, pg. 74) suggests illuminance levels considerably higher than those just cited for performing normal detail work over prolonger periods of time (20 to 50 ft-c); illuminances of from 10 to 20 ft-c are recommended for the same type of work conducted for shorter periods of time. Illuminance levels of from 2 to 10 ft-c are recommended for general illumination purposes. (Note: 1 ft-c is equivalent to 1 ft-L as long as the surface illuminated is a perfectly diffuse reflector).

Results from the present investigation have shown that an ambient illumination level of 8 ft-c is sufficient for most of the present performance tests. A future study will quantify visual performance on selected tests as a function of a variety of illuminance levels.

Other recommendations regarding interior surface finishes, reflectances, colors, etc. will be discussed in a later report from this laboratory.

A review of ambient luminance requirements in aircraft cockpits by Wulfeck et al. (Ref. 84, pg. 299) suggest that most visual performance measures do not degrade significantly until a luminance of about 0.05 ft-L. is reached; this is considered to be Mesopic Vision (about the lower limit of useful color vision) according to(Ref. 85, pg. 2-9).

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APPENDIX A

Table 6 through 32

Figure 16 through 33

Table 6

Mean Heart Rate[1] Results for
the Visual Acuity Test
(Subject JD)

Day Date	Illumination Condition		Mean Heart Rate During: Left eye test	Right eye test
M (8/10)	A		80	80
Tu (8/11)	A		78	77
W (8/12)	A		85	80
Th (8/13)	A		76	76
M (8/17)	A		85	84
Tu (8/18)	PF-R		90	81
F (8/21)	F		69	68
M (8/24)	F		80	77
Tu (8/25)	PF-L		79	77
Th (8/27)	PF-R		80	84
W (9/9)	PF-L		70	74
Th (9/10)	PF-R		80	80
	Ambient	Mean	80.8	79.4
		S.D.	4.1	3.1
	Sunlight	Mean	78.3	77.3
		S.D.	7.1	5.2

1. Beats per minute.

Table 7

Mean Heart Rate[1] Results for the
Visual Acuity Test

(Subject RM)

Day	Date	Illumination Condition		Mean Heart Rate During Left Eye Test	Mean Heart Rate During Right Eye Test
M	(8/10)	A		82	84
Tu	(8/11)	A		74	72
W	(8/12)	A		76	76
Th	(8/13)	A		83	85
M	(8/17)	A		83	80
Tu	(8/18)	PF-R		81	76
M	(8/24)	F		74	72
Tu	(8/25)	PF-L		73	74
W	(8/26)	F		81	79
Th	(8/27)	PF-R		77	85
W	(9/9)	PF-L		70	78
Th	(9/10)	PF-R		77	82
M	(9/14)	F		76	84
		Ambient	Mean	79.6	79.4
			S.D.	4.2	5.4
		Sunlight	Mean	76.1	78.8
			S.D.	3.8	4.7

1. Beats per minute;

Table 8

Mean Visual Fixation
Steadiness Test Results
(Subject JD)

Illumination Condition		30-second long segment			
		(a) First		(b) Last	
		Horiz.	Vert.	Horiz.	Vert.
Ambient	Mean+	5.4°	8.5°	5.4°	15.4°
	S.D.+	2.5°	5.3°	0.5°	14.3°
Sunlight	Mean∈	7.1°	8.0°	8.1°	10.1°
	S.D.∈	2.6°	1.8°	3.4°	4.1°

(Subject RM)

Ambient	Mean+	5.1°	6.3°	5.0°	4.1°
	S.D.+	2.8°	4.4°	1.7°	2.1°
Sunlight	Mean∈	7.1°	10.4°	5.4°	8.0°
	S.D.∈	3.7°	8.6°	1.8°	4.0°

+ Based upon 5, 30-second long measurement periods.

∈ Based upon 7, 30-second long measurement periods.

Table 9

Percentage of Blinks by Experimental Condition

(Subject JD)

30 Second Period	Ambient	Sunlight
First	41	15
Second	59	85
Total	100	100

Table 10

Percentage of Blinks by Experimental Condition

(Subject RM)

30 Second Period	Ambient	Sunlight
First	0	25
Second	100	75
Total	100	100

Table 11

Mean Heart Rate[1] and Total Blink

Results for the Visual Fixation

Steadiness Test

(Subject JD & RM)

Day	Date	Illumination Condition	Subject JD		Subject RM	
			$\bar{X}$ Heart Rate	Total Blinks	$\bar{X}$ Heart Rate	Total Blinks
M	8/10	A	90	58	90	3
Tu	8/11	A	92	58	80	8
W	8/12	A	88	55	86	9
Th	8/13	A	87	30	90	5
M	8/17	A	96	31	88	11
Tu	8/18	PF-R	97	58	84	13
F	8/21	F	80	5		
M	8/24	F	95	24	90	13
Tu	8/25	PF-L	87	9	84	11
W	8/26	F	-	-	81	26
Th	8/27	PF-R	92	15	87	4
W	9/9	PF-L	78	5	87	42
Th	9/10	PF-R	92	6	78	9
M	9/14	F	-	-	92	7
	Ambient	Mean	90.6	46.4	86.8	7.2
		S.D.	3.6	14.6	4.1	3.2
	Sunlight	Mean	88.7	17.4	86.8	13.1
		S.D.	7.3	19.1	4.7	12.1

1. Beats per minute.

Table 12

Mean Response Time Results to Peripheral Test Lights[1]

(Subject JD)

		Test Light Position							
		90°_L	60°_L	30°_L	0°	30°_R	60°_R	90°_R	30°_{up}
Ambient (N = 75)	Mean	883	799	722	655	763	787	846	837
	S.D.	661	374	294	193	363	449	543	428
Foveal (N = 30)	Mean	2116	2128	1306	1453	2558	2391	1983	1926
	S.D.	1227	986	682	770	1341	1255	1152	1064
Parafov. Left (N = 30)	Mean	1318	958	2037	789	956	900	1515	981
	S.D.	891	407	1441	397	648	363	1005	535
Parafov. Right (N = 45)	Mean	1863	1610	869	707	2923	3744	1967	1042
	S.D.	1187	1178	337	201	1179	802	1180	546

1. All values in milliseconds.

Table 13

Mean Response Time[1] Results to Peripheral Test Lights (Subject RM)

		Test Light Position							
		90° L	60° L	30° L	0°	30° R	60° R	90° R	30° up
Ambient (N = 75)	Mean	775	596	510	504	568	549	669	540
	S.D.	650	243	123	177	379	165	552	111
Foveal (N = 45)	Mean	1748	1086	795	1396	1512	1221	1627	1227
	S.D.	1095	814	343	1023	1067	788	1218	944
Parafov. Left (N = 30)	Mean	1817	829	2438	554	611	738	816	863
	S.D.	1305	536	1597	95	155	302	759	630
Parafov. Right (N = 45)	Mean	1619	733	688	570	2494	3291	1200	849
	S.D.	1097	205	211	96	1334	1094	925	370

1. All values in milliseconds.

Table 14

Location of Errors*
for the Peripheral Response Time Test

(Averaged Across subjects)

Illumination Condition	Test Light Position							
	90° L	60° L	30° L	0°	30° R	60° R	90° R	30° up
Ambient	2						1	
Foveal	8	5		2	16	7	12	
Parafoveal Left	5		22		1		3	
Parafoveal Right	12	6			32	70	10	

* Note: An error was scored if the subject did not detect the test light within 4 seconds.

Table 15

Mean Scan Time for the Central Ten Lines of the Visual Tracking (Straight Lines) Test

			Illumination			
			A	F	PF-L	PF-R
Subject	JD	Mean	2.35	1.93	1.84	1.87
		S.D.	0.23	0.00	0.09	0.10
	RM	Mean	1.69	1.60	1.49	1.52
		S.D.	0.09	0.29	0.13	0.13

Table 16

Mean Heart Rate and Total Blinks for the Visual Tracking (Straight Lines) Test

			Illumination			
			Ambient		Sunlight	
			Mean H.R.	Total Blinks	Mean H.R.	Total Blinks
Subject	JD		79.2	9[1]	83.0	17[1]
		S.D.	6.2	2.6	5.3	7.7
	RM		77.0	8	76.4	8
		S.D.	3.1	4.1	4.1	3.1

1 Differs from 1 at p = .05 level.

Table 17

Mean Scan Time[1] for the Visual Tracking (Curved Lines) Test.

(Subject JD)

Stimulus Card	Total Line length (inches)	Illumination			
		A	F	PF-L	PF-R
1	193.25	41.2	39.5	41.5	39.3
2	195.75	39.7	37.0	39.0	34.3
3	204.00	50.0	48.0	41.0	59.1
4	207.00	45.8	51.0	39.0	47.6
5	212.25	50.7	56.0	43.0	48.0
	Grand Mean	45.5	46.3	40.7	45.6

1. All values in seconds.

Table 18

Mean Scan Time[1] for the Visual Tracking (Curved Lines) Test

(Subject RM)

Stimulus Card	Total Line length (inches)	Illumination			
		A	F	PF-L	PF-R
1	193.25	29.5	26.0	25.5	34.0
2	195.75	27.6	25.0	24.5	27.0
3	204.00	37.3	32.3	47.0	35.3
4	207.00	37.7	34.0	35.5	36.3
5	212.25	39.6	39.6	37.0	38.6
	Grand Mean	34.4	31.4	33.9	34.2

1. All values in seconds.

Table 19

Mean Blink, Eye Closure[1], and Heart Rate[2] Results During the Visual Tracking (Curved Lines) Test

Stimulus Card Presentation Order	Subject: RM[3] Blinks	RM[3] Closures	RM[3] H.R.	Subject: JD[4] Blinks	JD[4] Closures	JD[4] H.R.
1st.	6.6	0.3	75.6	2.7	0	74.8
2nd	6.1	0.6	73.1	3.2	0.1	73.5
3rd	6.0	0.3	74.7	2.5	0	74.3
4th	6.1	0.1	74.3	2.2	0	75.1
5th	6.3	0.1	73.0	1.8	0.07	74.5

1. A maximum EOG deflection lasting 0.25 second or more.
2. Beats per minute.
3. Each data point based upon 12 days testing.
4. Each data point based upon 13 days testing.

Table 20

Mean Blink Rate Results for the Visual
Tracking (Curved Lines) Test

		Illumination			
		A	F	PF-L	PF-R
Subject JD	Mean	33.8[1]	67.0[2]	52.3[3]	52.0[4]
	S.D.	13.2	24.0	6.8	1.4
	N	25	10	15	10
Subject RM	Mean	16.7	21.3[1]	37.7	34.0[2]
	S.D.	7.1	8.5	9.3	18.4
	N	15	15	15	10

1 Differs from 2, 3, and 4 at $p < .05$ level.

Table 21 (a)

Mean Visual Search Time as a Function
of Letter Location and Illumination Condition

(Subject JD)

Angular Letter Separation**			Illumination Condition			
			A	F	PF-L	PF-R
16° 54' (4)*	Mean		5.53[1]	3.83[1]	4.29	3.90
	S.D.		0.69	0.24	1.64	0.99
	N		52	22	21	33
13° 12' (8)	Mean		4.32[2]	4.54[2]	4.61	4.63
	S.D.		0.32	0.80	1.44	1.09
	N		136	50	42	70
12° 00' (4)	Mean		4.72[3]	4.63[3]	4.37	3.45
	S.D.		0.76	0.34	1.42	0.93
	N		37	17	7	21
8° 27' (4)	Mean		5.13	3.96	4.15	4.65
	S.D.		0.59	1.10	1.39	0.39
	N		57	23	12	33
6° 00' (4)	Mean		4.34[4]	4.19[4]	5.03	4.19
	S.D.		1.23	0.36	1.79	1.08
	N		38	16	10	17

1 Differs from 2, 3, and 4 (within columns) at p = .05 level.

* Number in parenthesis indicates number of letters on each card at this angular distance from the center fixation position.

** Indicates the visual angle these letters were from the center fixation position.

Table 21 (b)

Mean Visual Search Time as a Function
of Letter Location and Illumination Condition

(Subject RM)

Angular Letter Separation**						
	16° 54' (4)	Mean	5.41[1]	5.90[1]	6.87[1]	5.07[1]
		S.D.	0.51	0.81	2.20	0.49
		N	58	31	15	31
	13° 12' (8)	Mean	5.48[2]	5.67	4.78	5.22[2]
		S.D.	0.91	1.11	1.39	0.86
		N	132	60	41	76
	12° 00' (4)	Mean	5.58[3]	6.26	4.70	4.85
		S.D.	0.81	0.96	1.89	0.63
		N	40	27	17	28
	8° 27' (4)	Mean	6.20[4]	4.90[2]	4.34[2]	5.18[3]
		S.D.	0.80	1.73	0.59	0.61
		N	62	30	23	36
	6° 00' (4)	Mean	6.36	6.00	5.14	5.08
		S.D.	1.56	1.65	3.08	2.43
		N	35	21	10	21

1.Differs from 2, 3, and 4 (within columns) at p = .05 level.

* Number in parenthesis indicates the number of letters on each card at this angular distance from the center fixation position.

** Indicates the visual angle these letters were from the center fixation position.

Table 22

Analysis of Initial Eye Movements for
the Visual Search Strategy Test

Subject	Half of Stimulus Card Analyzed		Illumination Condition A	F	PF-L	PF-R
Subject JD	Right Half[1]	Percent[*]	19	28	32	27
		Mean[**]	18.6	31.0	27.0	25.0
		S.D.	6.3	7.9	11.3	10.1
		N	93	62	54	75
	Left Half[1]	Percent	21	21	20	19
		Mean	22.2	22.5	16.5	15.7
		S.D.	5.4	6.4	0.7	4.5
		N	111	45	33	47
	Top Half[2]	Percent	18	10	9	22
		Mean	18.0	10.5	8.0	22.0
		S.D.	5.8	3.5	5.7	12.5
		N	90	21	16	66
	Bottom Half[2]	Percent	42	41	39	32
		Mean	42.2	48.0	33.5	33.3
		S.D.	4.9	5.7	23.3	8.7
		N	211	96	67	100
Subject RM	Right Half[1]	Percent	13	13	15	18
		Mean	12.4	10.0	13.0[3]	19.7
		S.D.	5.0	3.6	5.7	3.1
		N	62	30	26	59
	Left Half[1]	Percent	28	23	20	24
		Mean	33.6	19.3	15.0[3]	24.7
		S.D.	13.9	5.9	5.7	9.3
		N	156	58	30	74
	Top Half[2]	Percent	15	11	24	22
		Mean	14.0	9.0	21.5	21.7
		S.D.	8.7	4.6	10.6	10.8
		N	70	27	43	65
	Bottom Half[2]	Percent	44	53	41	36
		Mean	42.2	43.3	31.5	38.3
		S.D.	13.1	8.3	20.5	21.1
		N	211	130	63	115

Footnotes on next page.

Table 22
(continued)

Footnotes:

1. Right half means differ from the left half means at p = .001 level.
2. Top half means differ from the bottom half means at p = .001 level except for the two means labelled 3 which were not statistically significant.

* Sums to 100 percent within columns.

** Indicates mean number of eye movements for each condition noted.

Table 23

Mean Visual Search Time for Letters
within each Half of the Stimulus Card

Subject	Half of Stimulus Card Analyzed		Illumination Condition: A	F	PF-L	PF-R
JD	Right Half	Mean[5]	4.96[1]	4.23[2]	4.24[3]	4.14[4]
		S.D.[5]	1.84	2.23	1.94	1.48
		N	137	62	45	72
	Left Half	Mean	4.63[1]	4.39	4.58	4.40[2]
		S.D.	2.25	2.19	1.38	1.50
		N	132	57	52	75
	Top Half	Mean	4.72[1]	4.20[2]	4.59	4.51
		S.D.	0.87	1.64	1.23	0.75
		N	133	55	36	81
	Bottom Half	Mean	4.85	4.27	4.45	4.29
		S.D.	1.44	0.88	1.77	0.77
		N	162	61	83	58
RM	Right Half	Mean	5.87[1]	5.99[2]	5.08[3]	5.26[4]
		S.D.	2.65	2.64	2.20	1.84
		N	124	66	78	45
	Left Half	Mean	5.21[1]	5.97	4.63[2]	4.89
		S.D.	2.05	3.08	1.69	1.96
		N	142	76	46	86
	Top Half	Mean	5.86[1]	5.54	4.24[2]	5.18[3]
		S.D.	1.03	0.90	0.98	1.66
		N	136	70	45	79
	Bottom Half	Mean	6.32	5.77	6.61	5.45
		S.D.	1.72	1.46	2.02	1.09
		N	164	79	45	91

1 differs from 2,3, and 4 at $p < .05$ level (comparisons only made across the four illumination conditions).

5. All values in seconds.

Table 24

Visual Search Time[5] Grand Means
for the Visual Search Strategy Test

		Illumination Condition			
		A	F	PF-L	PF-R
Subject JD	Grand Mean	4.79[1]	4.30[2]	4.42[3]	4.32[4]
	S.D.	2.54	2.18	2.62	2.42
	N	319	128	101	174
Subject RM	Grand Mean	5.77[1]	5.99	5.18[2]	5.22[3]
	S.D.	3.63	3.80	3.35	3.06
	N	327	159	106	192

1 differs from 2,3, & 4 at $p = .05$ level

5. All values in seconds.

Table 25

Mean Heart Rate and Blink Results for the
Hand Steadiness Test

(Subject JD)

Day (Date)	Illumination Condition	Mean Heart Rate		Total Blinks	
		First[1]	Second[2]	First[1]	Second[2]
M (8/10/70)	A	84.5	74.9	30	64
Tu (8/11)	A	89.6	71.6	25	17
W (8/12)	A	84.9	70.7	45	4
Th (8/13)	A	80.3	69.8	5	1
M (8/17)	A	97.4	79.1	4	2
Tu (8/18)	PF-R	89.0	73.3	4	5
F (8/21)	F	70.8	68.1	0	6
M (8/24)	F	84.2	71.6	6	6
Tu (8/25)	PF-L	79.6	70.7	7	2
Th (8/27)	PF-R	81.9	81.9	6	2
W (9/9)	PF-L	74.9	69.5	2	6
Th (9/10)	PF-R	87.5	77.5	4	15
	Ambient Mean	87.4[3]	73.2[3]	21.8[5]	17.6
	S.D.	6.5	3.8	17.4	26.7
	Sunlight Mean	81.1[4]	73.3[4]	4.1[5]	6.0
	S.D.	6.6	4.9	2.5	4.3

1. First test administration each day.
2. Second test administration each day.
3 Differs from 3 at p = .01 level.
4 Differs from 4 and 5 at p = .05 level.
5 Differs from 5 at p = .05 level.

Table 26

Mean Heart Rate and Blink Results for
the Hand Steadiness Test

(Subject RM)

Day (Date)		Illumination Condition	Mean Heart Rate First[1]	Mean Heart Rate Second[2]	Total Blinks First[1]	Total Blinks Second[2]
M	(8/10/70)	A	85.8	78.5	0	1
Tu	(8/11)	A	76.3	75.3	1	7
W	(8/12)	A	80.5	76.6	8	6
Th	(8/13)	A	90.4	81.1	0	20
M	(8/17)	A	89.0	83.0	0	17
Tu	(8/18)	PF-R	84.7	75.9	1	6
M	(8/24)	F	80.5	72.8	7	4
Tu	(8/25)	PF-L	82.2	82.5	1	8
W	(8/26)	F	90.3	81.6	6	5
Th	(8/27)	PF-R	87.8	81.3	2	11
W	(9/9)	PF-L	89.4	83.3	10	22
Th	(9/10)	PF-R	79.2	70.4	6	8
M	(9/14)	F	87.5	72.7	1	6
		Ambient Mean	84.4	78.9	1.8	10.2
		S.D.	5.9	3.1	3.5	8.0
		Sunlight Mean	85.2[3]	77.6[3]	4.2	8.8
		S.D.	4.2	5.2	3.4	5.8

1 = First test administration each day.

2 = Second test administration each day.

3 differs from 3 at the p = .01 level.

Table 27

Mean Results for the Body Balance Battery
(Subject JD)

Test		Eyes	Ambient Illumination			Solar Simulator On		
			Mean	S.D.	N	Mean	S.D.	N
Standing Tests (Two feet floor contact)	Sharpened Romberg	Open	60.0	0	9	60.0	0	7
		Closed	60.0	0	9	60.0	0	7
	R on Rail	Open	60.0	0	9	60.0	0	7
		Closed	27.2	7.86	9	23.3	2.89	7
Standing Tests (One foot floor contact)	OLRB-Right	Open	60.0	0	9	60.0	0	7
		Closed	30.0	0	9	26.3	6.18	7
	OLRB-Left	Open	60.0	0	9	60.0	0	7
		Closed	29.9	0.32	9	27.3	3.41	7
Walking Tests	Rail Walk $^{\epsilon}$	Open	74.8	0.83	4	69.5	11.43	6
		Closed	61.2	19.08	9	56.0	19.07	7

Notes: ϵ The rail walk test was scored both on the basis of distance walked on the rail and total time using the formula: $B = 10D/T$ where B = rail walk score, D = distance (feet) walked on the rail, T = time (seconds) subject balanced on rail.

Table 28

Mean Results from the Body Balance Battery
(Subject RM)

Test		Eyes	Ambient Illumination			Solar Simulator On		
			Mean	S.D.	N	Mean	S.D.	N
Standing Tests (Two feet floor contact)	Sharpened Romberg	Open	60	0	9	60	0	8
		Closed	57.6	6.91	9	55	8.89	8
Standing Tests (One foot floor contact)	R on Rail	Open	52.2[1]	15.98	9	34.9	21.07	8
		Closed	7.1[1]	4.41	9	27.2	7.86	9
	OLRB-Right	Open	56.7[1]	6.25	9	51.9[1]	14.13	8
		Closed	12.8[1]	3.85	9	11.0[1]	6.09	7
	OLRB-Left	Open	60.0[1]	0	9	59.6[1]	0.99	8
		Closed	9.3[1]	5.87	9	11.3[1]	7.42	7
Walking Test	Rail Walk ϵ	Open	67.0[1]	3.67	4	53.1[2]	15.54	7
		Closed	30.7[1]	11.39	9	31.6[2]	15.35	7

Note: ϵ The rail walk test was scored both on the basis of distance (D) in feet and total time (T) (seconds) the subject stayed on the rail using the formula: $B = 10D/T$.

1 Differs from 1 (within cells) at the $p = .001$ level.

2 Differs from 2 at the $p = .05$ level.

Table 29

Mean Heart Rate* for Body Balance Tests

(Subject JD)

Test			Eyes	Ambient Illumination		Sunlight	
				Mean	S.D.	Mean	S.D.
Standing Tests	(Two foot contact)	Sharpened Romb.	Open	86.6	4.82	86.7	5.56
			Closed	88.0	6.75	86.1	5.90
		Romb. on Rail	Open	92.2	8.67	84.4^{1}	4.83
			Closed	94.0	15.70	94.1^{1}	4.30
	(One foot contact)	OLRB-Right	Open	81.4^{2}	7.86	82.6^{3}	3.46
			Closed	93.6^{2}	3.85	94.4^{3}	10.92
		OLRB-Left	Open	84.6^{4}	5.81	86.6^{5}	4.76
			Closed	98.8^{4}	10.18	99.0^{5}	9.80
Walking Tests		Rail Walkε	Open	110.0	10.46	98.4	9.50
			Closed	112.4	17.36	106.6	6.90

Notes: *Beats per minute

εThe rail walk test score (B) was based upon distance (D) walked on the rail (in feet) as well as total time (T) the subject remained on the rail (in seconds) using the formula: $B = 10D/T$.

1 Differs from 1 at the $p = .01$ level.

2,3,5 Differ from 2,3,5 (respectively) at the $p = .02$ level.

4 Differs from 4 at the $p = .05$ level.

Table 30

Mean Heart Rate* for Body Balance Tests

(Subject RM)

Test		Eyes	Ambient Illumination		Sunlight	
			Mean	S.D.	Mean	S.D.
Standing Tests (Two feet contact)	Sharpened Romb.	Open	81.6	4.34	79.0	3.66
		Closed	84.0	3.94	82.6	3.29
	Romb. on Rail	Open	92.6	3.13	88.8	3.65
		Closed	91.0	6.52	90.8	4.13
Standing Tests (One foot contact)	OLRB-Right	Open	92.6[1]	4.51	87.1[1]	3.27
		Closed	92.4	6.23	91.4	5.50
	OLRB-Left	Open	86.0	5.70	86.2	2.12
		Closed	86.2	6.69	90.0	5.10
Walking Tests	Rail Walk ε	Open	99.6[2]	3.05	94.0[2]	5.42
		Closed	98.4	5.32	94.2	4.50

Notes: * Beats per minute.

ε The rail walk test score (B) was based both upon distance (D) walked on the rail (in feet) as well as total time (T) the subject stayed on the rail (in seconds) using the formula: $B = 10D/T$.

1 Differs from 1 and 2 differs from 2 at the $p = .05$ level.

Table 31

Results for the Precision
Eye-Hand Coordination Test
(Horizontal and Vertical Pattern Orientation)

Mean Number		Illumination Condition							
		A		F		PF-L		PF-R	
		JD	RM	JD	RM	JD	RM	JD	RM
Attempted	Mean	57.2[1,2]	53.4[4]	50.0	50.2	59.2	59.7	57.0	57.6[4]
	S.D.	5.8	5.9	8.0	11.5	5.0	4.8	9.5	8.3
Correct	Mean	38.7[5]	40.6[6]	42.5[5]	28.2[6]	44.7	33.6	45.6	38.3
	S.D.	6.5	7.5	2.5	11.4	3.6	11.4	4.9	12.6
Errors	Mean	18.2	12.2	16.5	22.0	14.5	26.2	11.3	19.0
	S.D.	9.5	10.9	15.7	21.5	5.2	13.0	6.2	4.7
	N[3]	34	26	4	6	6	6	4	4

Notes: 1. All values in seconds.
2. Maximum score = 100.
3. Number of times test was presented.
4,5, 6 Differ from 4,5,6 (respectively) at $p < .05$ level.

Table 32

Precision Eye-Hand Coordination Test Results
as a Function of Direction of Eye-Hand Movement[1]

(Stimulus Card Oriented Vertically)

			Illumination Condition							
			A		F		PF-L		PF-R	
			L-R[1]	R-L	L-R	R-L	L-R	R-L	L-R	R-L
Subject	JD	Mean	58.6	52.2	70.0	54.0	63.0	57.0	66.0	56.5
		S.D.	4.5	6.2	0.0	0.0	8.5	0.0	0.0	3.5
		N[2]	11	6	1	1	2	1	1	2
		E[3]	31.3	11.4	4.5	2.0	3.0	28.0	11.2	8.6
	RM	Mean	59.1	54.9	61.0	42.0	69.0	57.0	62.0	61.5
		S.D.	5.8	6.6	0.0	9.9	0.0	0.0	0.0	3.5
		N	8	5	1	2	1	1	1	2
		E	22.3	28.0	10.2	5.2	3.3	9.5	14.2	7.3

Notes: 1. Left to right (right to left) eye-hand movement.

2. N = number of individual card presentations.

3. E = percentage of total errors made under each condition.

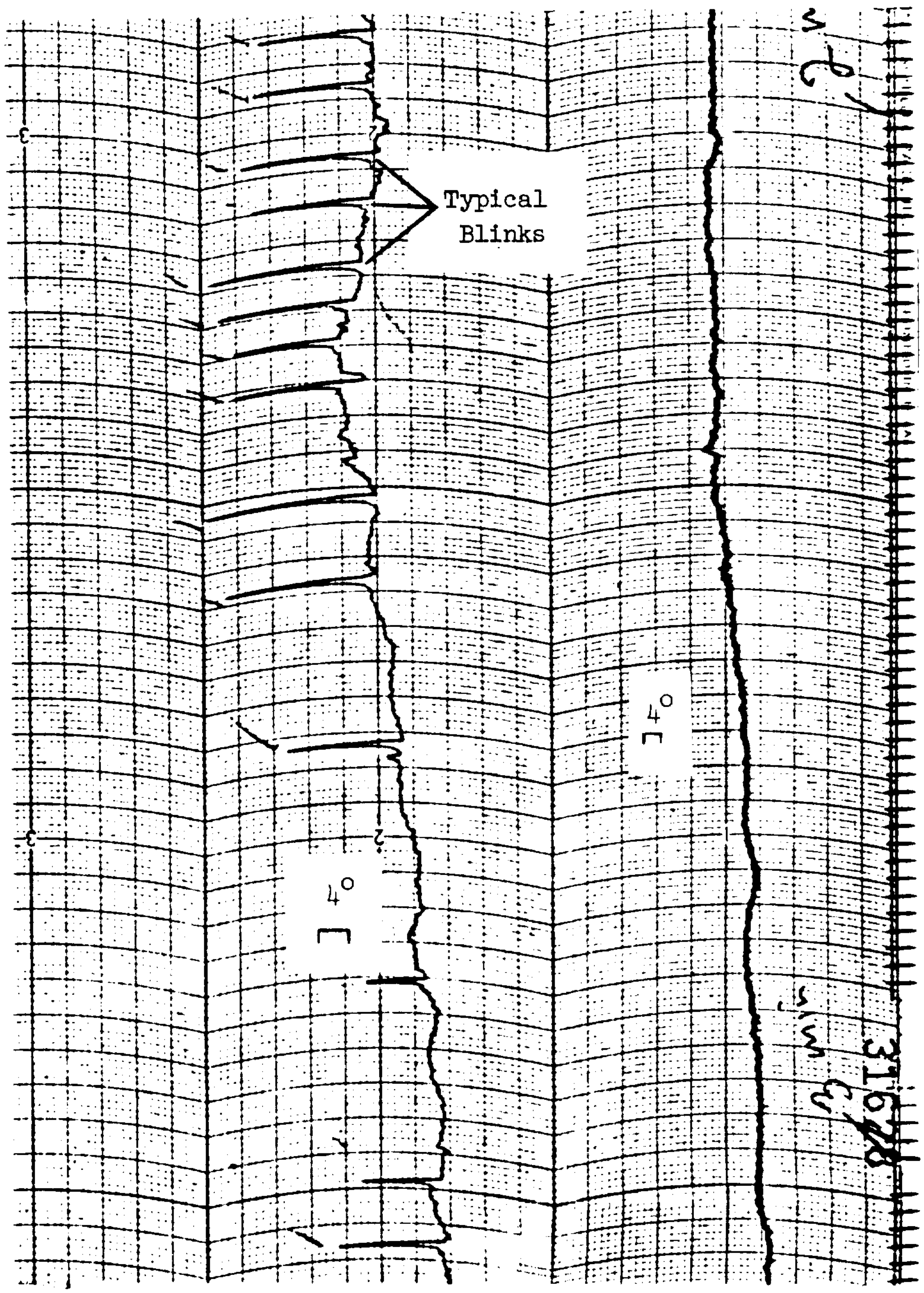
Figure 16

Typical EOG Record During the

Visual Fixation Steadiness Test

(Subject JD)

Foveal Illumination



Vertical
(Up) Movement (Down)

Horizontal
(Right) Movement (Left)

Figure 17

Peripheral Response Time Results

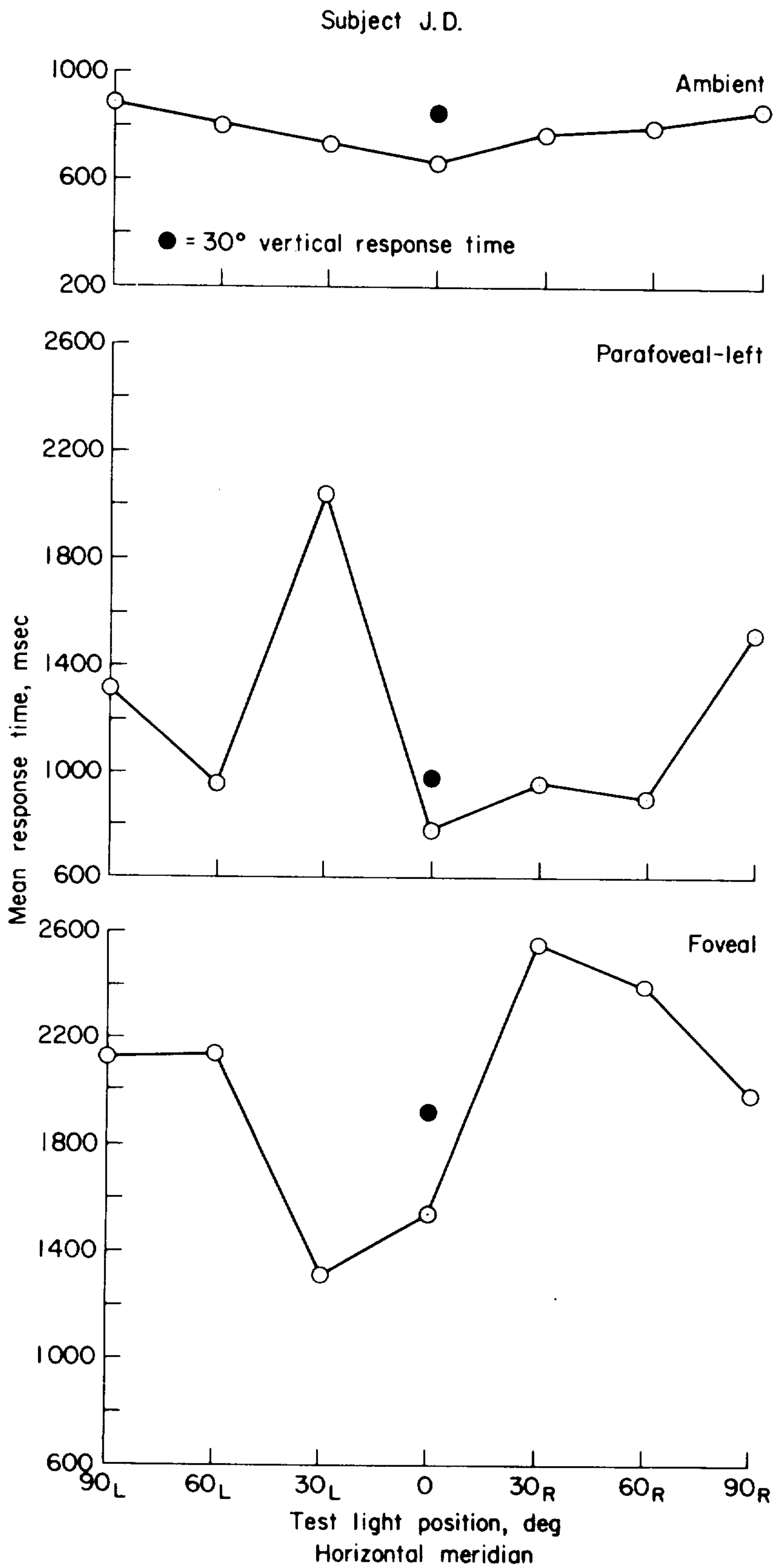


Figure 18

Peripheral Response Time Results

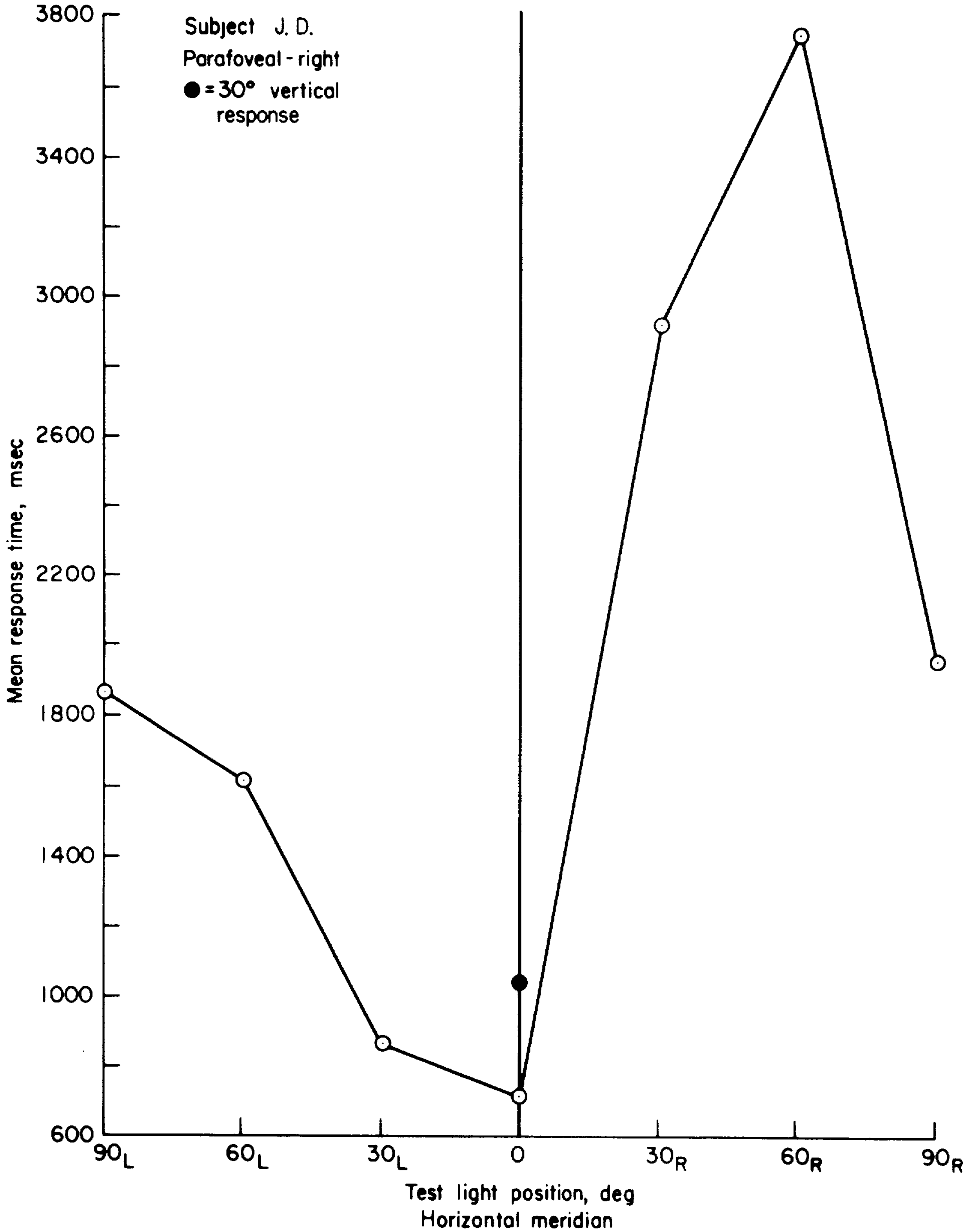


Figure 19

Peripheral Response Time Results

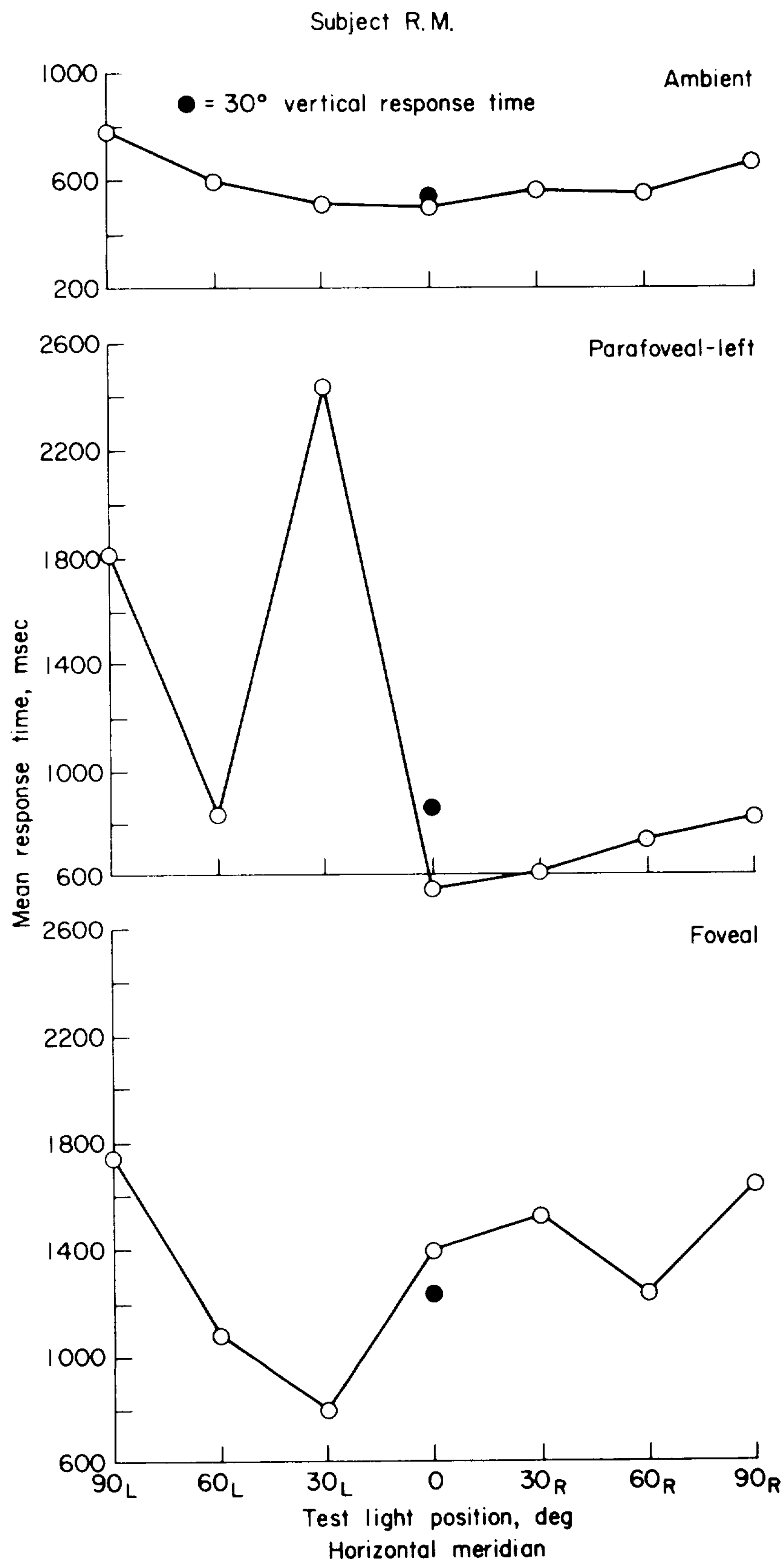


Figure 20

Peripheral Response Time Results

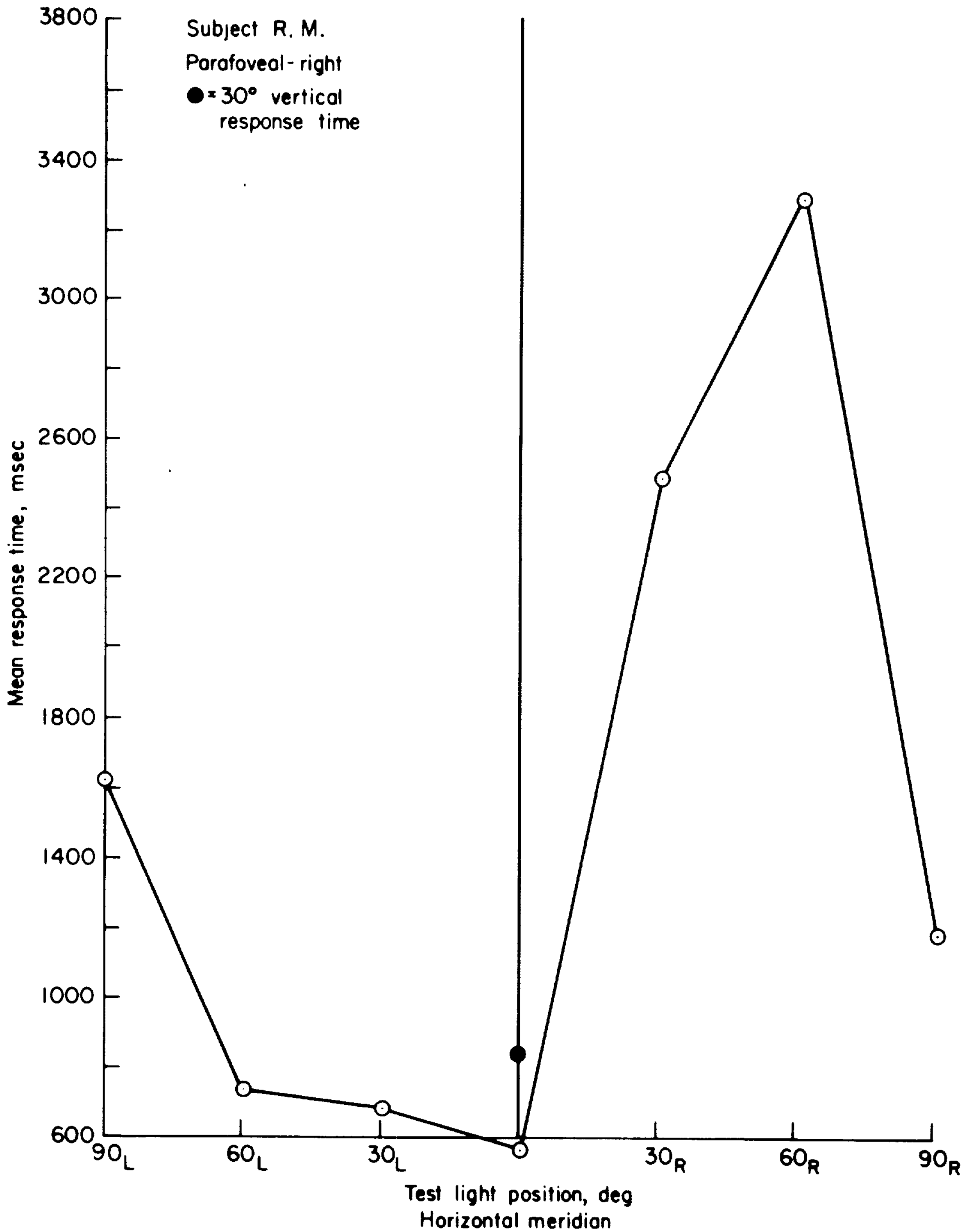


Figure 21

Visual Search Strategy Results

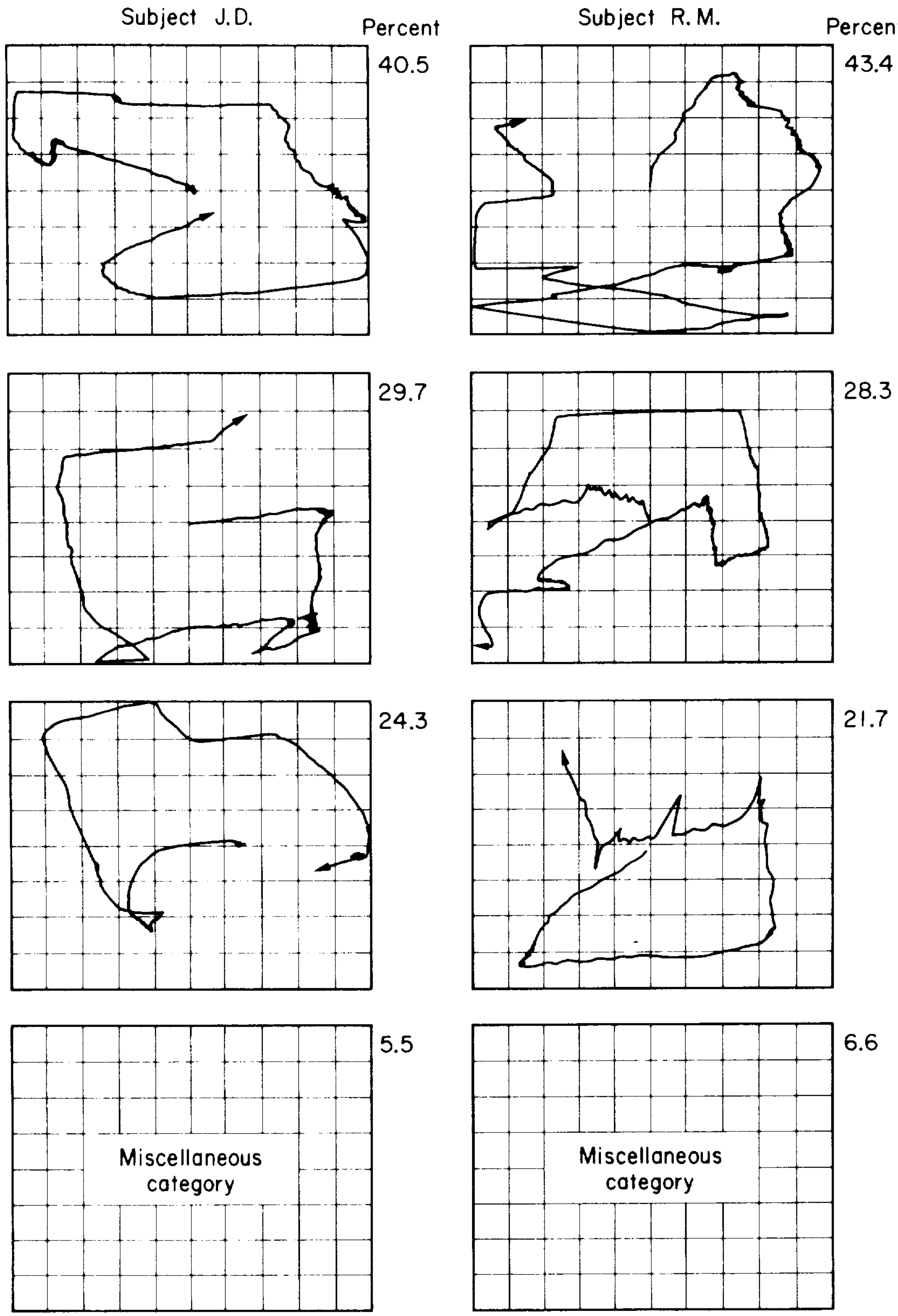


Figure 22

Mean Hand Steadiness Results

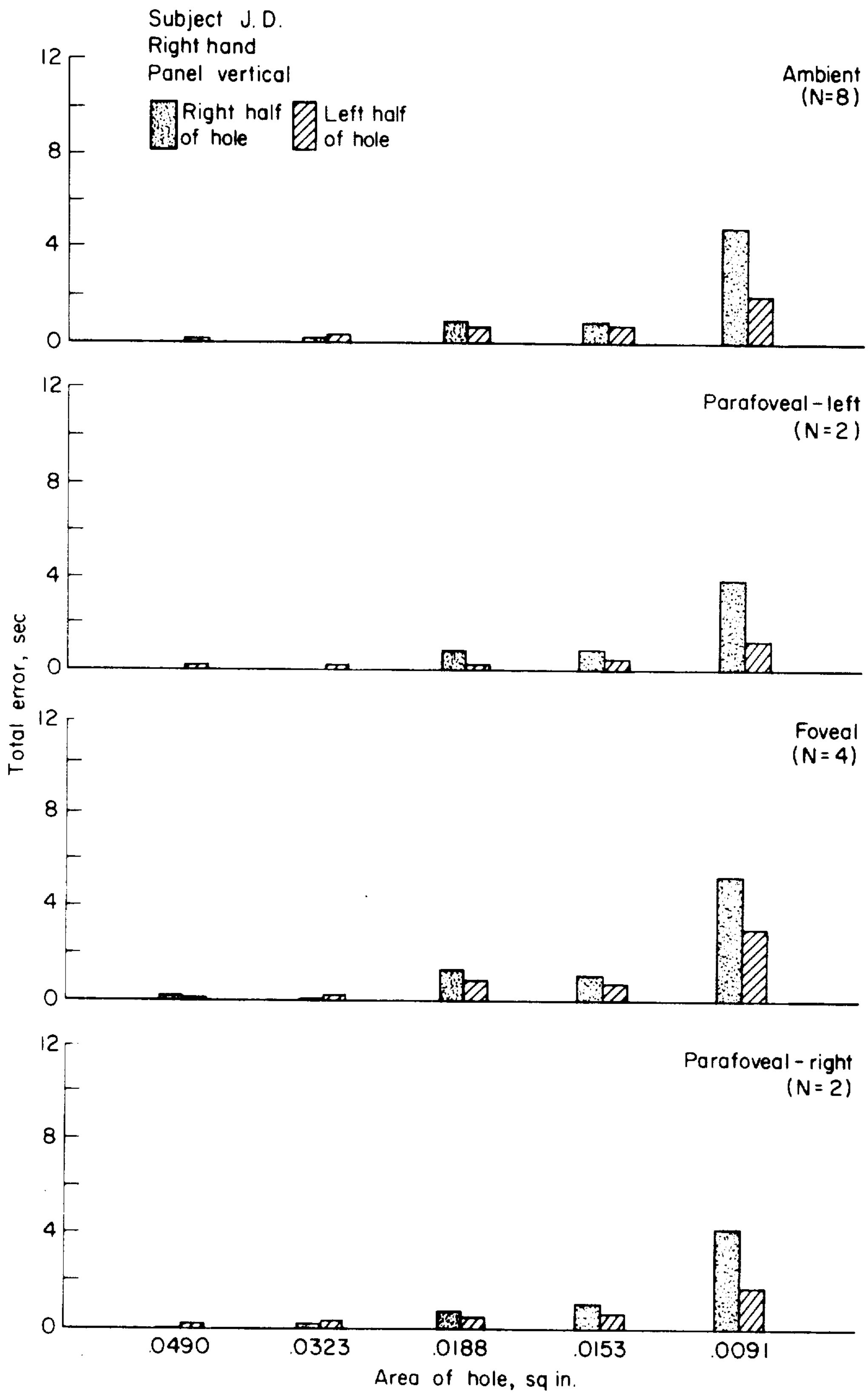


Figure 23

Mean Hand Steadiness Results

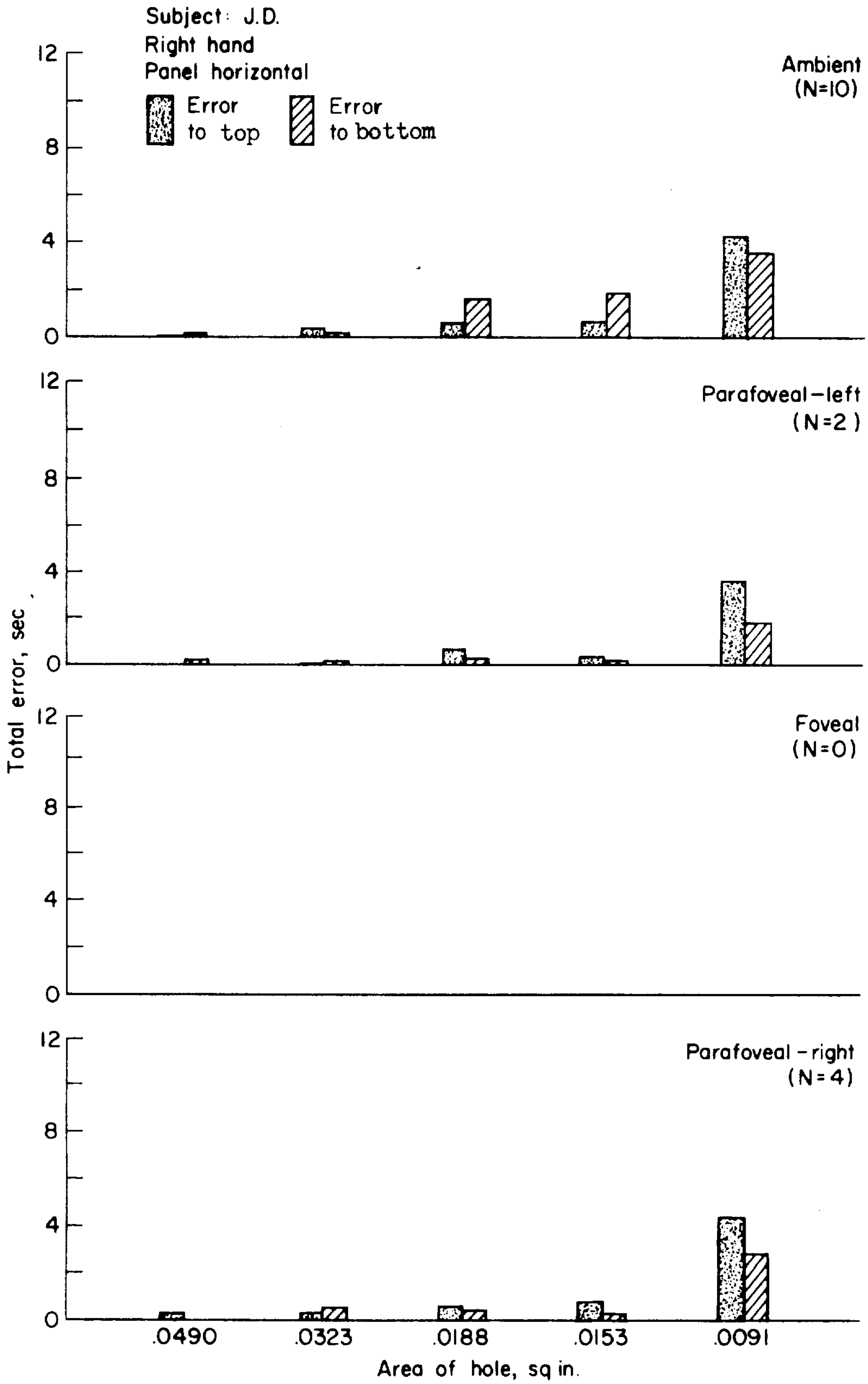


Figure 24

Mean Hand Steadiness Results

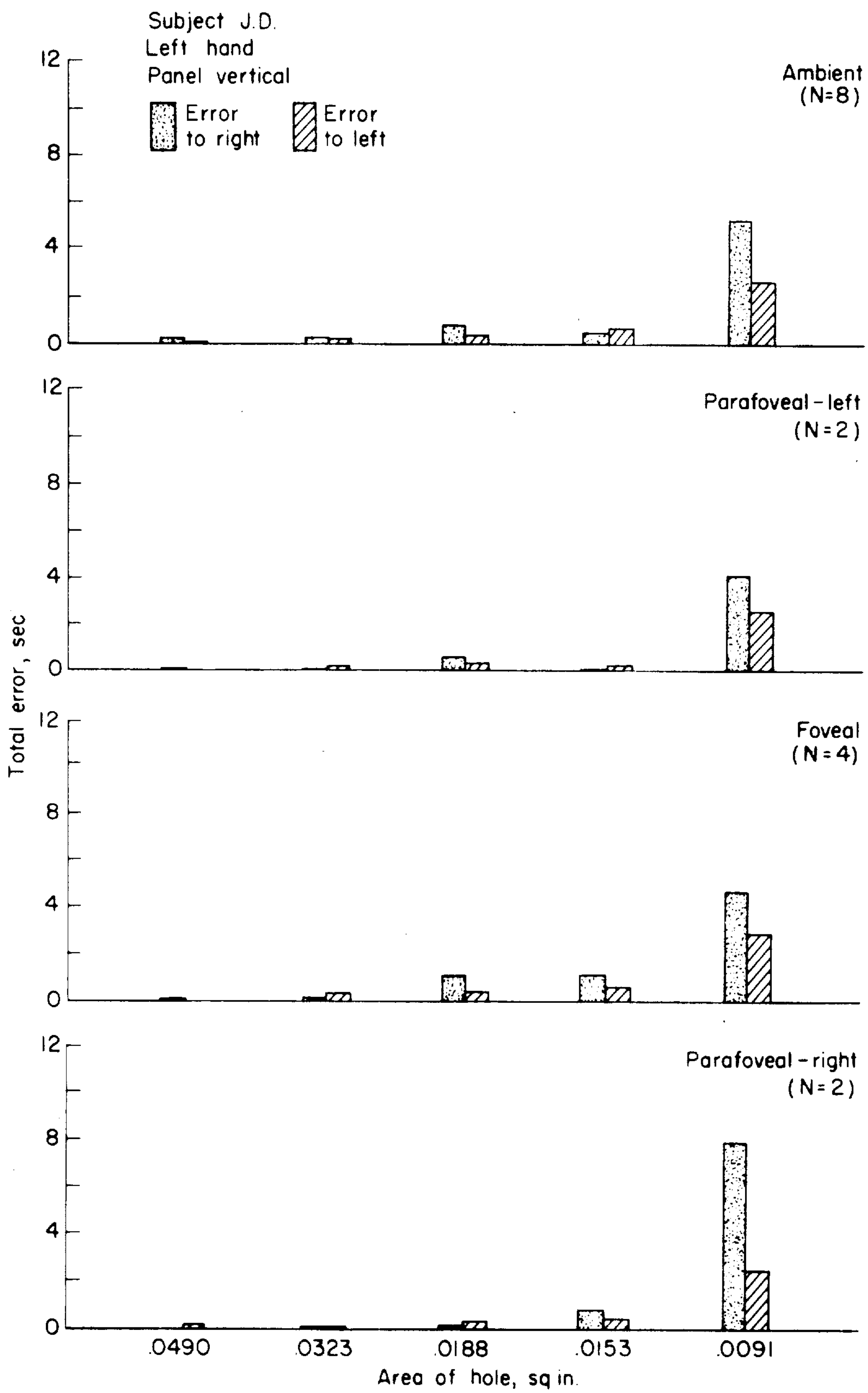


Figure 25

Mean Hand Steadiness Results

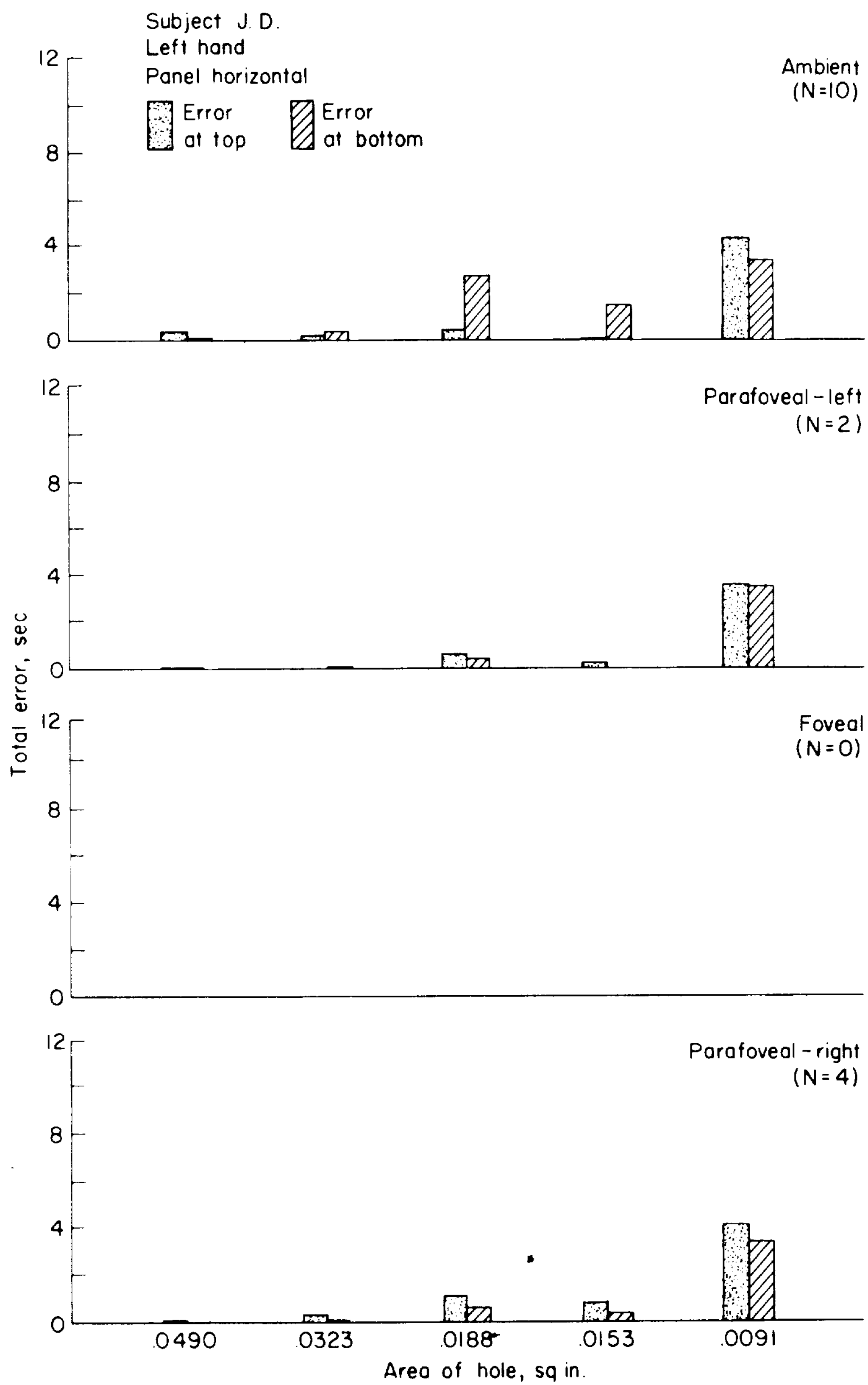


Figure 26

Mean Hand Steadiness Results

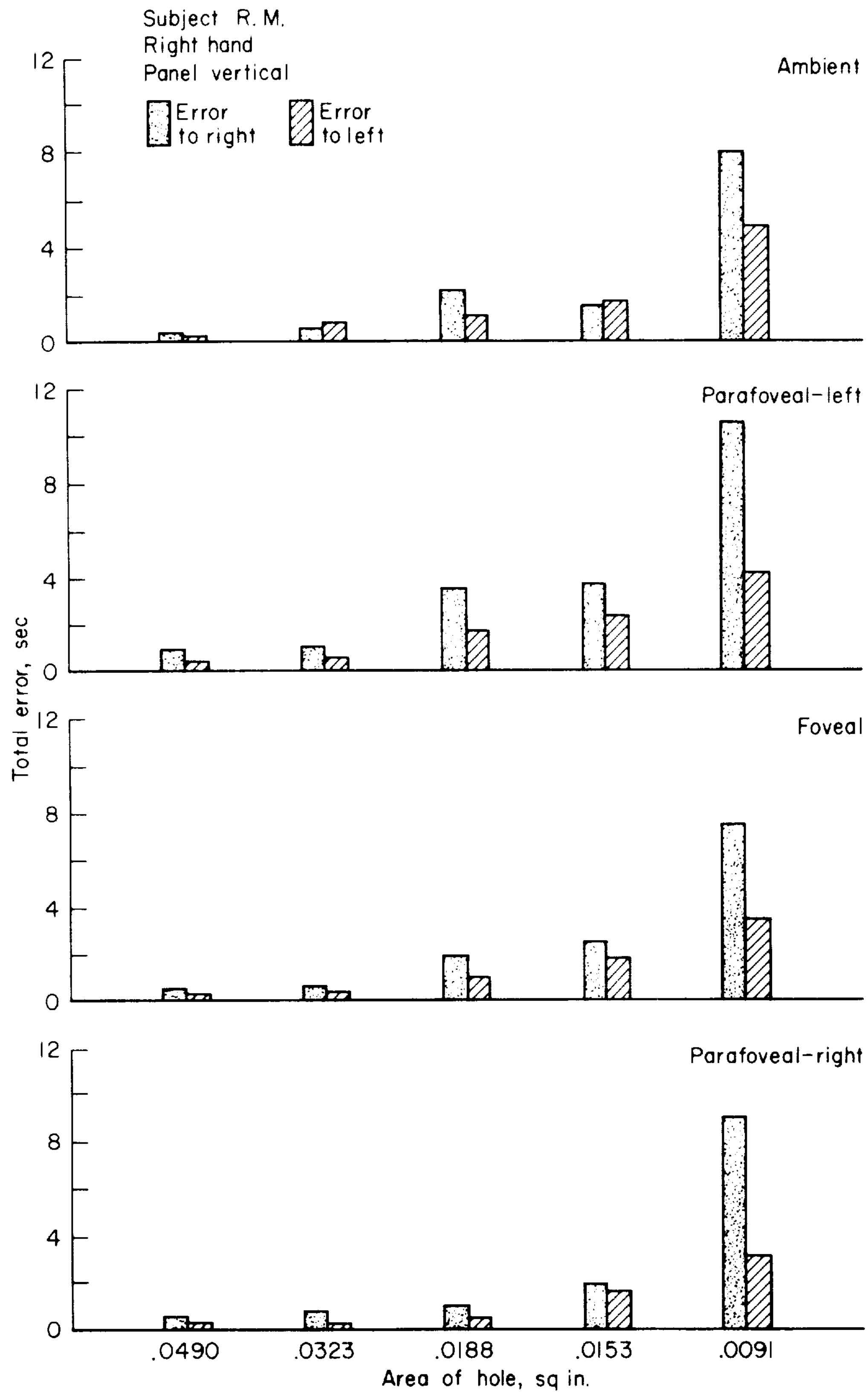


Figure 27

Mean Hand Steadiness Results

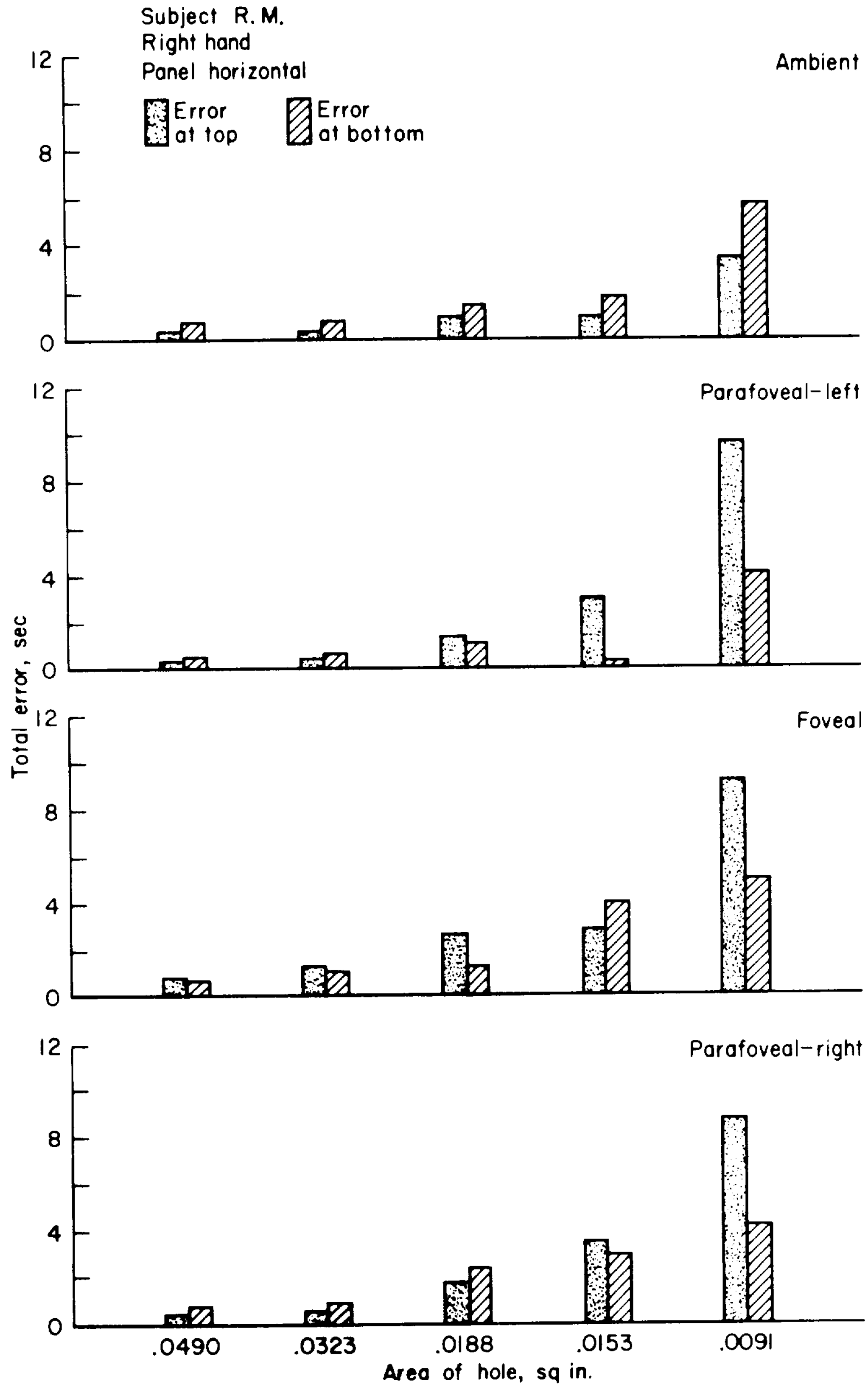


Figure 28

Mean Hand Steadiness Results

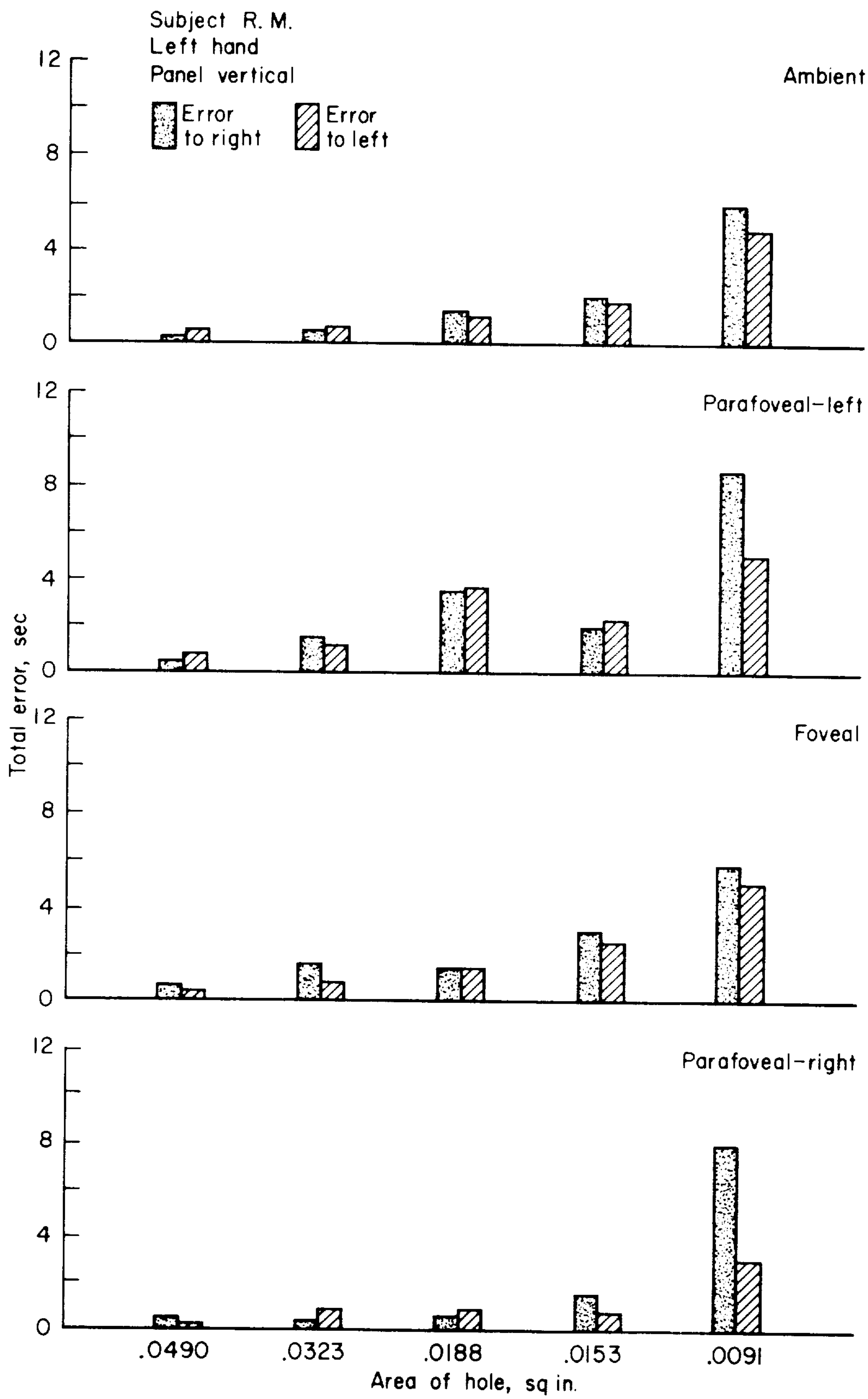
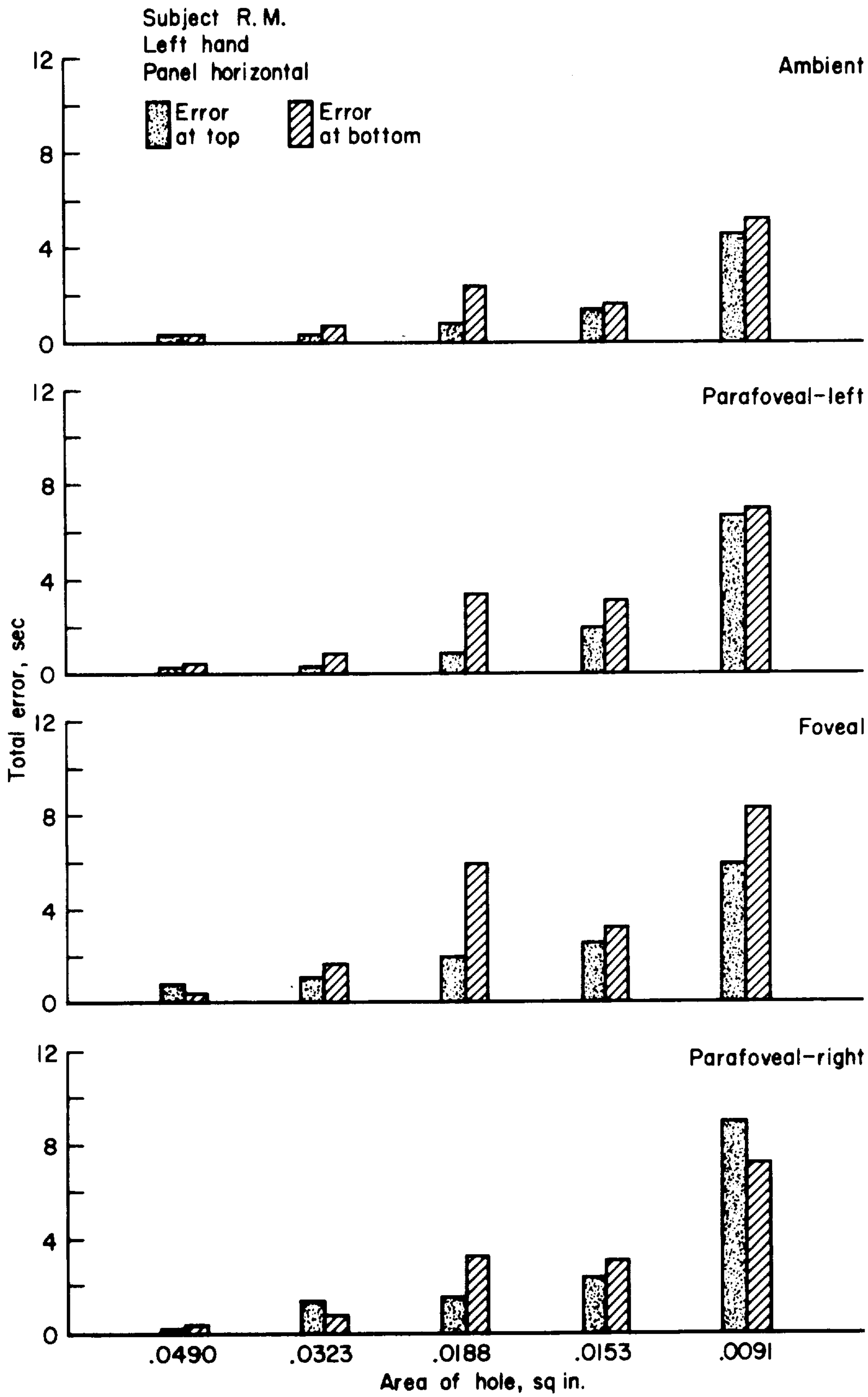


Figure 29

Mean Hand Steadiness Results



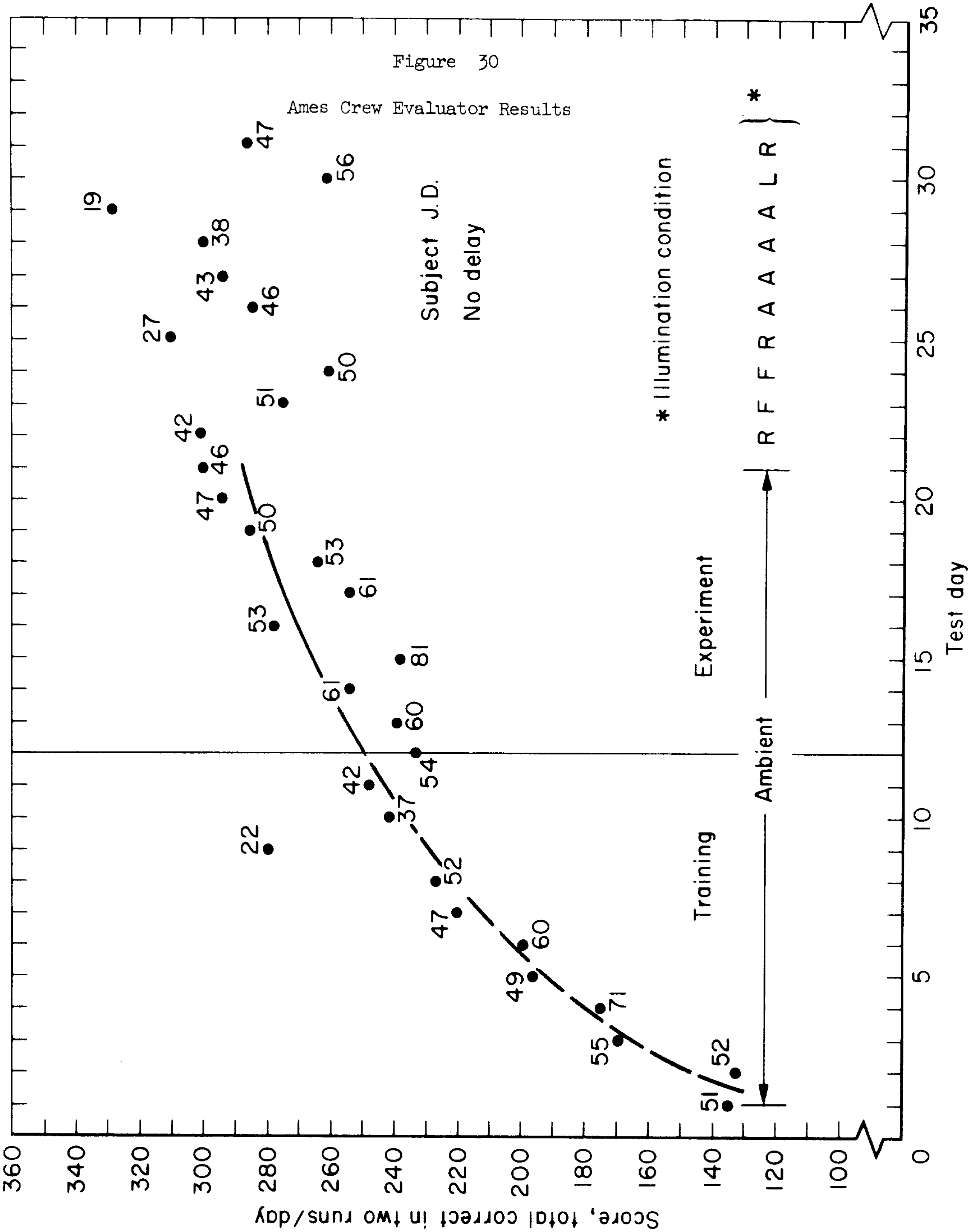
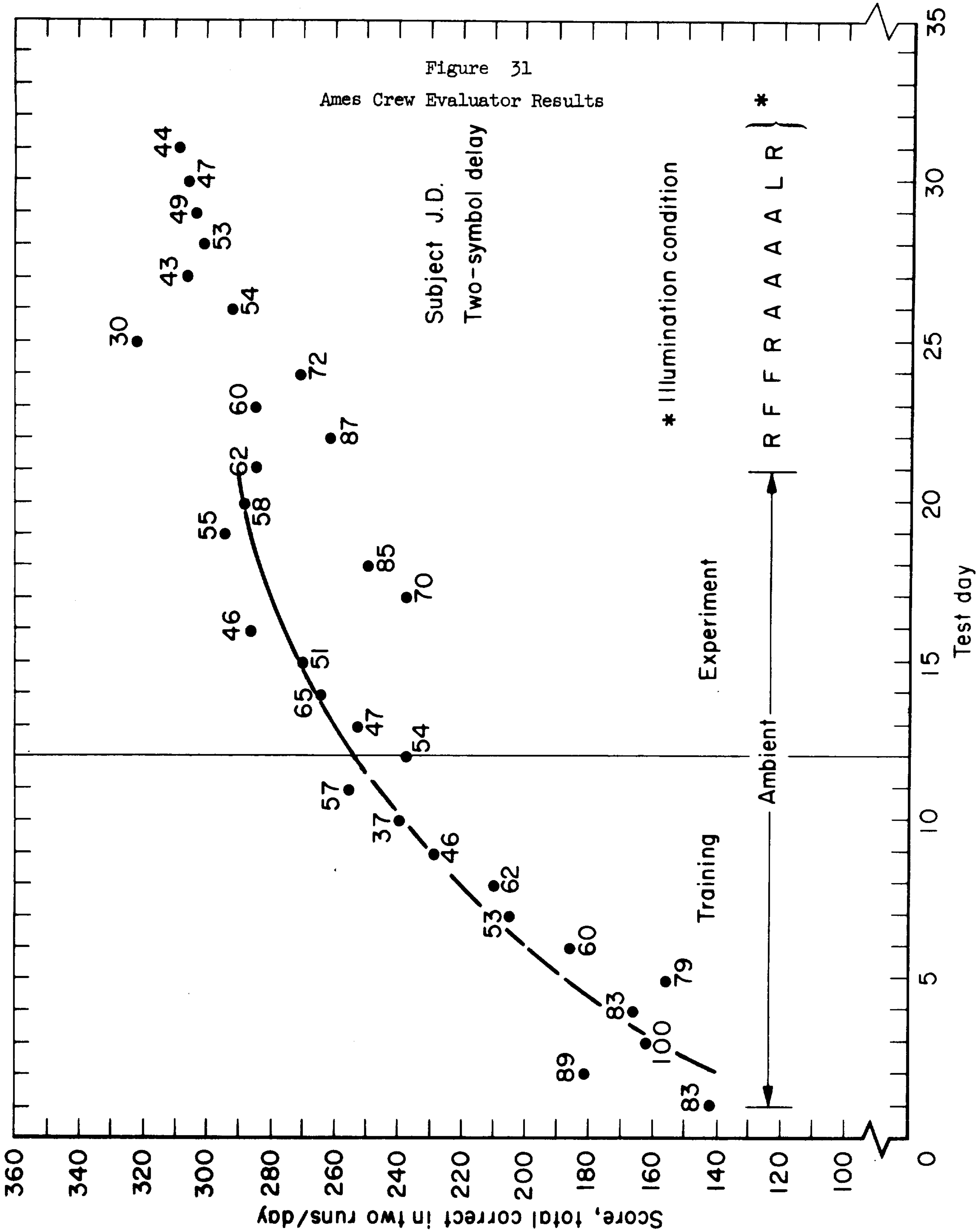


Figure 30

Ames Crew Evaluator Results

Figure 31

Ames Crew Evaluator Results



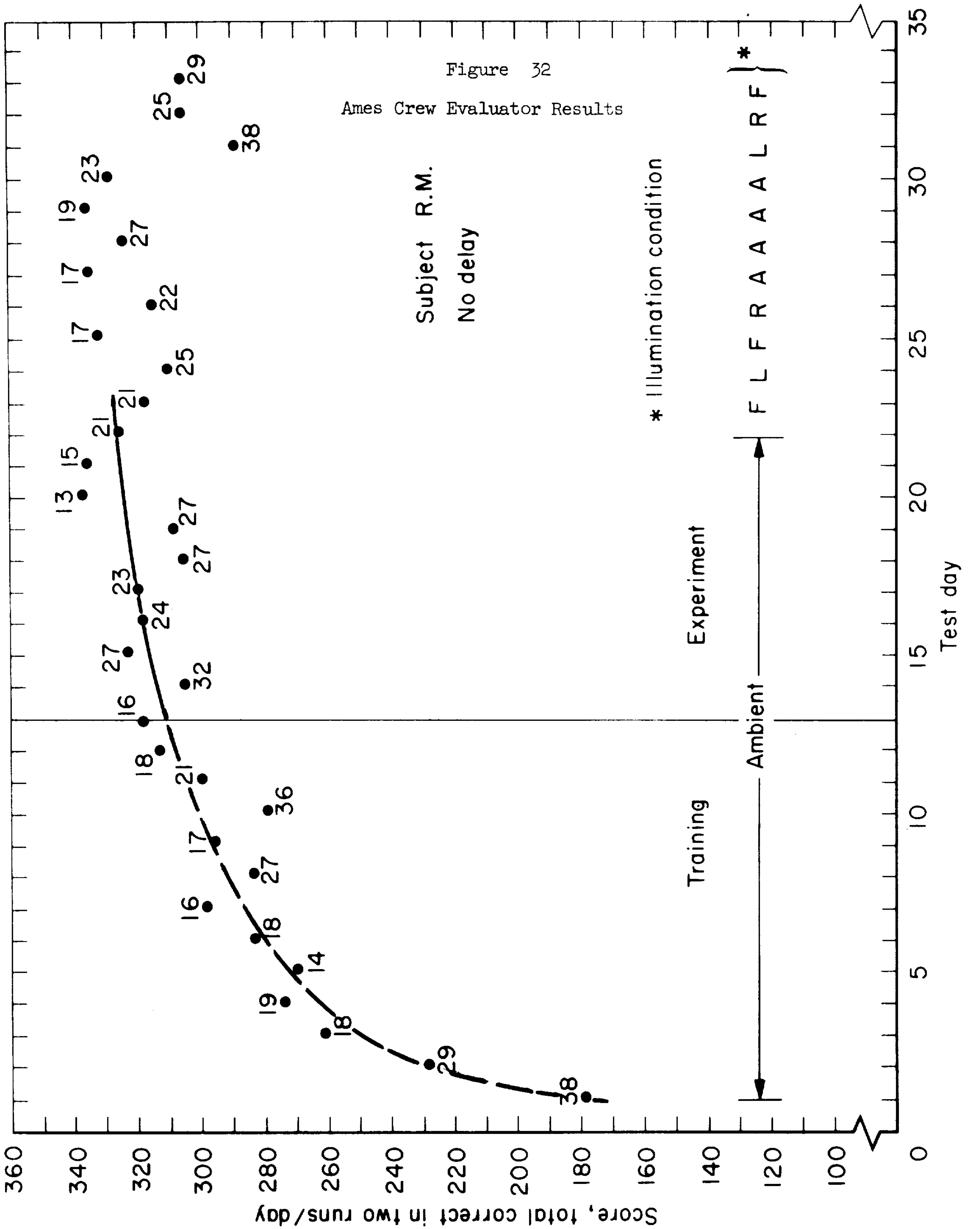


Figure 32

Ames Crew Evaluator Results

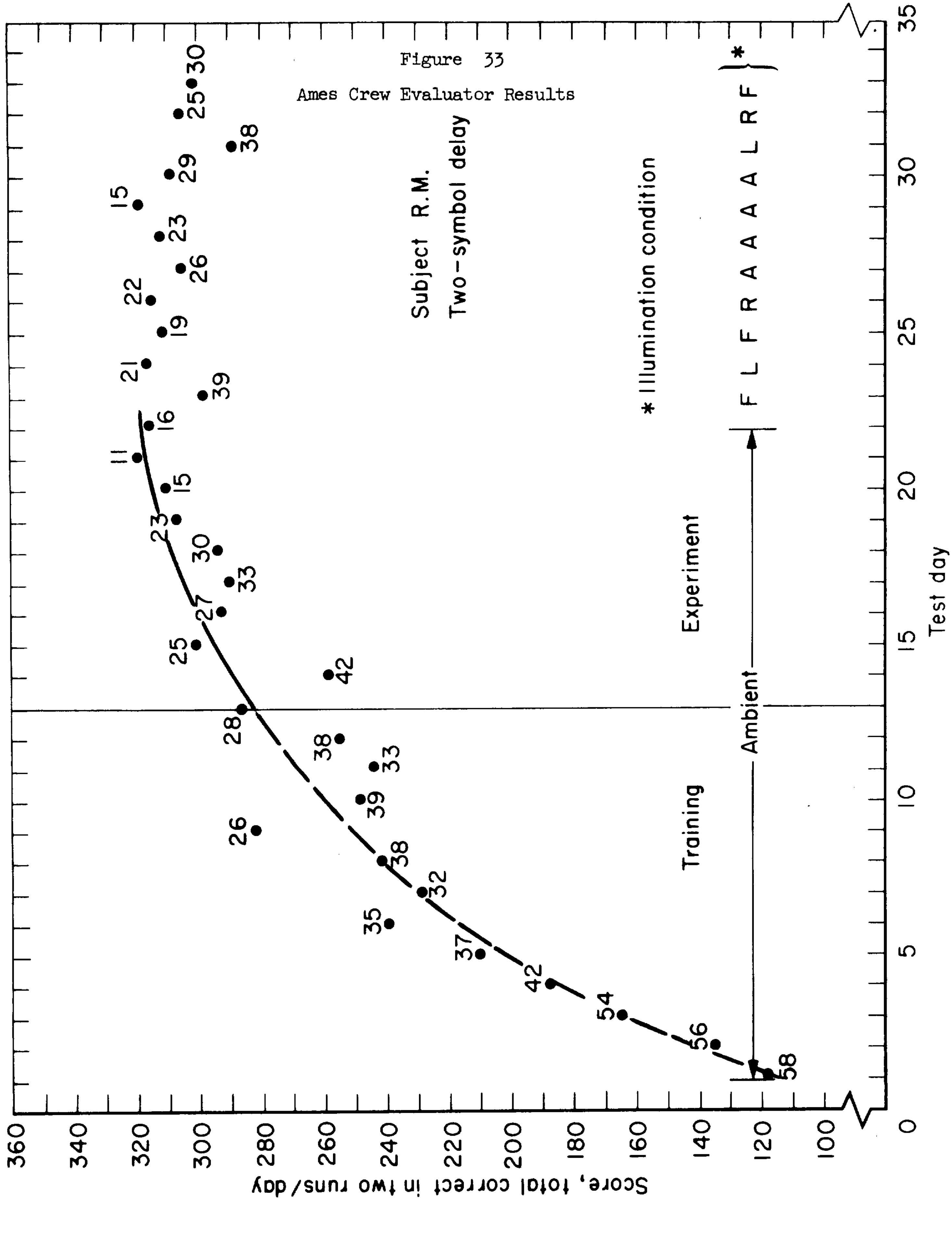


Figure 33

Ames Crew Evaluator Results

APPENDIX B

Personality Test Scores

Both subjects were given a battery of personality, achievement, and other tests prior to their involvement in the present investigation. The same test battery was also administered to a group of 78 junior college students to provide normative "baseline" data. The following table presents the present subject's test scores as percentiles normalized against the junior college sample. Scores from the various tests which were administered have been grouped according to common personality features. The original test instrument is indicated by reference numbers related to footnote references.

Table 34

Personality Test Scores for each Subject

Test (see key)	J.D. Score	J.D. Percentile	R.M. Score	R.M. Percentile
Active (1)	9	37	6	15
Active (2)	6	91	6	91
Vigorous (1)	19	100	12	45
Dominant (1)	11	72	3	13
Thrill (2)	12	78	11	65
Political (3)	53	100	38	28
Impulsive (1)	15	91	10	35
Worry Wart (2)	2	24	10	87
Reflective (1)	11	78	8	46
Theoretical (3)	35	9	56	100
Aesthetic (3)	36	16	44	53
Religious (3)	36	63	23	15

Table 34
(continued)

Sociable (1)	12	67	13	77
Sociable (2)	3	49	6	96
Social (3)	36	33	46	80

Footnotes: (Test instrument key)

1. Thurstone Temperment Schedule, Science Research Associates, 1949.
2. Meyers Inventory,
3. Allport, Vernon, Lindzey Study of Values, Houghton-Mifflin Co., Boston, 1960.